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PhD Thesis

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A biomechanical approach to improve health among professional violinists using a novel ergonomic chinrest

The ergonomics of playing the violin

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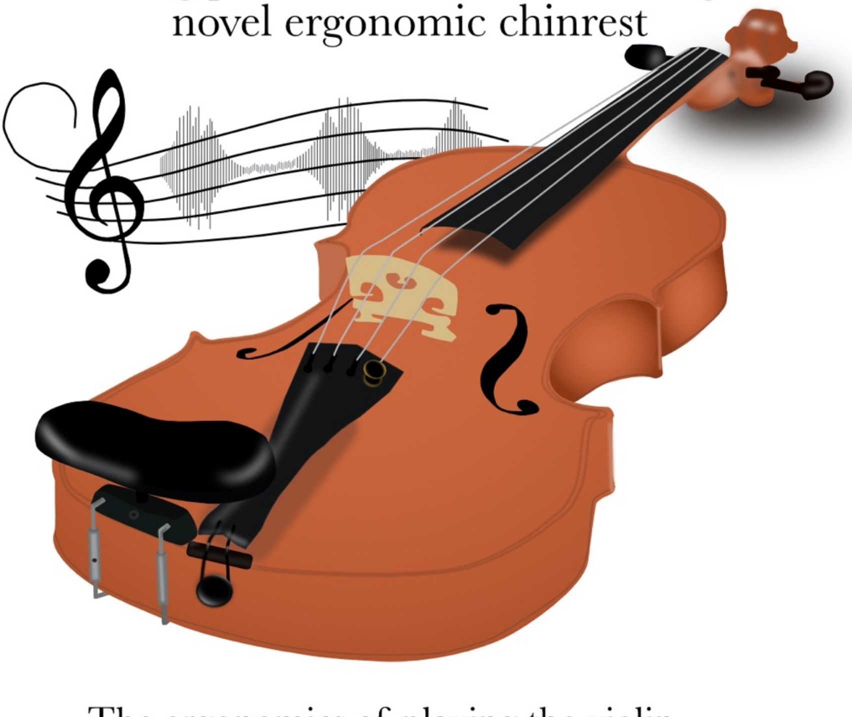

The ergonomics of playing the violin

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List of papers

This PhD thesis is based on the following submitted and peer-reviewed papers.

Paper I
Mann S, Andersen LN, Paarup HM.
Preliminary Feasibility and Acceptability Examination of Using a Novel Ergonomic Chinrest with a Low Shoulder Rest by a Viola Player: Case Report
Manuscript: In review in Med Probl Perform Art, July 2023, MPPA-2023-7-4-1 - (17)

Paper II
Mann S, Juhl CB, Paarup HM, Søgaard K.
Measuring the usability of a novel ergonomic chinrest during violin playing: a feasibility study.
WORK, doi:10.3233/WOR-220518

Paper III
Mann S, Olsen HB, Paarup HM, Søgaard K.
The effects of an ergonomic chinrest among professional violin players. A biomechanical investigation in a randomised crossover design.
Appl Ergon. 2023; 27;110:104018. doi: 10.1016/j.apergo.2023.104018

Paper IV
Mann S, Paarup HM, Søgaard K.
The user experience of violinists playing with a novel ergonomic chinrest: An evaluation on motivation, usage behaviour, usability and acceptance.
Manuscript: Submitted to WORK, July 2023, WOR-230389

Preface

My motivation to pursue this PhD stems from an early passion for working with classical musicians. As someone who has played piano, violin, and viola since a young age, I struggled to find resources to help me adjust my instrument to my body posture and anthropometrics. This experience led me to become a physiotherapist to learn how to help musicians best. During my physiotherapy education, I discovered a need for more knowledge regarding musicians' unique needs and physical problems, both in Denmark and worldwide. Preventing injuries and playing-related pains in musicians is crucial for enabling them to continue their musical education and careers for a long and sustainable life.

The scientific work presented in this dissertation was conducted at the Department of Sports Science and Clinical Biomechanics, Faculty of Health Sciences, at the University of Southern Denmark, in collaboration with the musician's clinic at Odense University Hospital. I had the guidance of my principal supervisor, Professor Karen Søgaard, and my co-supervisors, Lars Brandt, MD, PhD, and Helene Martina Paarup, MD, PhD. The project was made possible through the generous financial support of Helsefonden, Axel Muusfeldts Fund, the Region of Southern Denmark, and the Faculty of Health Sciences at SDU.

This PhD project was conducted during the Covid-19 pandemic, which significantly impacted the scope of the research. Two of the three studies presented in this dissertation experienced multiple postponements due to the pandemic, and the ongoing crisis also influenced the recruitment process. As the first author, I also underwent a four-month sick leave, affecting the project timeline. Despite these numerous challenges, I am delighted to present a PhD dissertation that addresses a research gap in the field of playing ergonomics among violinists.

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1 ABBREVIATIONS

EC	Ergonomic chinrest (In Study III EC refers to the ergonomic chinrest played with low shoulder rest)
SR	Ergonomic chinrest with low shoulder rest
WSR	Ergonomic chinrest without shoulder rest
UC	Usual chinrest and shoulder rest
PRMD	Playing-related musculoskeletal disorders
QA	Questionnaire
RULA	Rapid Upper Limb Assessment tool
ISO	The International Organization for Standardization
CARE	The case-report guidelines
TIDieR	The Template for Intervention Description and Replication
NRS	Numerical Rating Scale
EMG	Electromyography
MVIC	Maximal voluntary isometric electrical contractions
MVE	Maximum voluntary electrical activity
APDF	Amplitude probability distribution Function
EVA	Exposure variation analysis
UT	The upper trapezius
NE	The upper neck extensor
SCM	The sternocleidomastoideus
DT	The left anterior deltoid and right medial deltoid
LNL	The lateral neck length
SD	Standard Deviation
IQR	Interquartile range

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4 Summary

Violinists constitute a substantial proportion of classical musicians in symphony orchestras. Especially, violin playing involves asymmetrical seating posture and prolonged, repetitive work, which includes static muscle activity. As a result, violinists are particularly prone to playing-related musculoskeletal disorders, experiencing higher pain rates ranging from 64.1% to 90% compared to other musicians. The consequences of such disorders have wide-ranging effects on individuals and society. Inability to perform on their instrument can result in sickness absence and, in the worst case, early termination of employment, leading to increased healthcare expenses and reduced productivity.

Many violinists use supportive ergonomic equipment such as chinrests and shoulder rests to alleviate discomfort and improve the interface between the violin and the player, especially in the left shoulder and neck muscles. However, studies have shown that even with the widespread use of such equipment, many violinists still experience pain. Furthermore, there is a lack of consensus on how to effectively use these products to decrease muscle activity or change neck posture. Additionally, the understanding of violinists' perceptions regarding the usability of these products in terms of performance and comfort is limited.

This PhD dissertation commenced with a systematic online search for an ergonomic chinrest (EC) that largely incorporates all necessary features to accommodate a player's anthropometrics, especially an aligned neck posture. Subsequently, three studies were conducted with the following objectives: 1) examining the preliminary feasibility and acceptability of the selected EC, 2) investigating the feasibility of playing the violin with the EC, with or without a low shoulder rest, and 3) investigating the effects on upper body kinematics and muscle activity when using the EC compared to the participants' usual chinrest and shoulder rest. Additionally, the user experience of the EC was explored to identify potential barriers and facilitators.

The first study involved a case study on the feasibility of using the EC for six weeks. Data on usage, performance, comfort, pain, and fatigue were collected. The instructional materials were found not to be feasible, requiring the implementation of online guidance for installation and usage from the product developer. Compliance with using the EC was high, and positive feedback was received regarding its effects on performance and comfort. However, the case experienced pain and fatigue throughout the six weeks. Still, the case reported no pain or fatigue at the end and expressed being positive toward using the EC in the future.

Based on the case study results, pain-free violinists were recruited for the following studies. The second was a feasibility study conducted over two weeks involving six violinists. It aimed to assess the usability of the EC utilising questionnaires evaluating various factors such as usage, performance, comfort, adjustment, confidence, sound quality, and written user feedback. The EC demonstrated high use; however, playing without a shoulder rest was deemed unfeasible due to significantly lower performance, longer confidence-building time, and more negative feedback. Additionally, all six participants met the compliance criterion when playing with a shoulder rest, whereas two participants did not meet the criterion when playing without it. Consequently, the EC with a low shoulder rest was chosen for further testing.

The third and final study investigated the effects of the EC on upper-body muscle activity, neck kinematics and the user experience of EC. This study involved 38 professional violinists and used electromyography, three-dimensional motion capture and questionnaires. The comparison between the EC and the participants' usual chinrest and shoulder rest revealed only minor differences, including less left rotation of the head (3.3°), increased neck extension (1.3°), and slightly lower muscle activity (0.5-1.0 %MVE). No significant biomechanical differences were observed, and overall, the EC maintained static muscle activity (4-10 %MVE) across all muscles. The user experience of the EC demonstrated a solid drive to improve posture, reduce muscle tension, and enhance performance. Although usability issues such as product appearance, adjustment time, and sound impact were identified, 37% of participants expressed intentions to continue using the EC after the study.

In conclusion, this particular EC proved feasible for use with a low shoulder rest. However, no substantial changes were found in neck posture or muscle activity compared to the participants' usual chinrest and shoulder rest. Various usability issues were identified, which can inform the design process of the EC or other ergonomic products. Therefore, this specific EC cannot be recommended as a superior alternative to violinists' usual ergonomic chinrests. Nevertheless, developing solutions supporting individuals' needs remains crucial to ensure their satisfaction.

Future studies may explore other innovative ergonomic solutions, alternative interventions such as micro-breaks, or incorporating active and specific training during rehearsals. Furthermore, it is important to investigate and understand the changes in health behaviour among violinists and identify the necessary factors to enhance their well-being.

5 Danish Resumé

Violinister udgør en væsentlig del af klassiske musikere i symfoniorkestre. Violinspil indebærer især asymmetrisk siddestilling og langvarigt gentaget arbejde, der omfatter statisk muskelaktivitet. Som følge heraf er violinister særligt, udsatte for at opleve muskuloskeletale lidelser relateret til spil, hvor smertefrekvensen er højere og spænder fra 64,1% til 90% sammenlignet med andre musikere. Konsekvenserne af disse lidelser kan have vidtrækkende effekter både for individet og samfundet. Manglende evne til at spille på deres instrument kan resultere i sygefravær og i værste fald tidlig ophør af ansættelsen, hvilket medfører øgede sundhedsudgifter og reduceret produktivitet.

Mange violinister anvender ergonomisk udstyr som hagebræt og skulderstøtter til at lindre ubehag og forbedre kontakten mellem violin og spiller, især i venstre skulder og nakke muskler. Imidlertid har undersøgelser vist, at mange violinister stadig oplever smerter, selv når de bruger sådant udstyr. Derudover er der ingen konsensus om, hvordan man effektivt kan bruge disse produkter til at opnå gavnlige ændringer i nedsat muskelaktivitet eller ændret nakkeposition. Der er også begrænset forståelse for violinisters opfattelse af brugervenligheden af disse produkter med hensyn til præstation og komfort.

Denne ph.d.-afhandling startede med en systematisk online søgning efter et ergonomisk hagebræt (EB), der indeholder alle nødvendige justeringer i ét produkt og sigter mod at imødekomme spillerens antropometri, især en lige nakkeposition. Derefter blev tre studier udført med følgende formål: 1) en forudgående undersøgelse om der kan gennemføres at spille med valgte EB og accepten af den, 2) at undersøge om det er muligt at gennemføre muligheden for at spille violin med EB med eller uden en lav skulderstøtte, og 3) at undersøge effekten på overkroppens kinematik og muskelaktivitet ved brug af EB sammenlignet med deltagernes sædvanlige hagebræt og skulderstøtte. Derudover blev brugeroplevelsen af EB undersøgt for at identificere potentielle barrierer og facilitatorer.

Det første studie involverede et casestudie om gennemførbarheden af at bruge EB i seks uger. Data om brug, præstation, komfort, smerte og træthed blev indsamlet. Det viste sig, at instruktionsmaterialerne ikke var anvendelige, hvilket krævede implementering af online-vejledning til installation og brug fra produktudvikleren. Brugen af EB var høj, og der blev modtaget positiv feedback vedrørende dens virkninger på præstation og komfort. Imidlertid oplevede casen smerter og træthed i løbet af de seks uger, men rapporterede ingen smerte eller træthed ved afslutningen og udtrykte positiv holdning til at bruge EB i fremtiden.

Baseret på resultaterne fra casestudiet blev smertefrie violinister rekrutteret til de efterfølgende studier. Det andet studie var et gennemførbarheds studie over to uger med seks violinister. Formålet var at vurdere brugervenligheden af EB ved hjælp af spørgeskemaer til at evaluere forskellige faktorer som brug, præstation, komfort, justering, tillid, lydkvalitet og skriftligt feedback. EB blev anvendt meget, men det blev vurderet, at det ikke var gennemførbart at spille uden en skulderstøtte på grund af markant lavere præstation, længere tid til opbygning af tillid og mere negativ feedback. Desuden opfyldte alle seks deltagere kriteriet om minimum brug, når de spillede med en skulderstøtte, mens to deltagere ikke opfyldte kriteriet, når de spillede uden skulderstøtte. Derfor blev EB med en lav skulderstøtte valgt til yderligere test.
Det tredje og sidste studie undersøgte effekten af EB på muskelaktivitet i overkroppen, nakke kinematik og brugeroplevelsen af EB. Dette studie omfattede 38 professionelle violinister. Der blev anvendt elektromyografi, tredimensionelle bevægelsesoptagelser og spørgeskemaer. Sammenligningen mellem EB og deltagernes sædvanlige hagebræt og skulderstøtte viste kun mindre forskelle, herunder mindre rotation af hovedet mod venstre (3,3°), øget ekstension af nakken (1,3°) og lidt lavere muskelaktivitet (0,5-1,0 %MVE). Der blev ikke observeret væsentlige biomekaniske forskelle, og den statisk muskelaktivitet (4-10 %MVE) på tværs af alle muskler blev bibeholdt ved brugen af EB. Forventningen til at anvende EB viste en stærk motivation for at forbedre holdning, reducere muskelspændinger og forbedre præstationen. Selvom der blev identificeret problemer med brugervenligheden såsom produktets udseende, justeringstiden og indvirkning på lyden, gav 37% af deltagerne udtryk for at ville fortsætte med at bruge EB efter studiet.
Konklusionen er at dette specifikke EB kan anvendes med en lav skulderstøtte. Dog blev der ikke fundet væsentlige ændringer i nakke eller muskelaktivitet sammenlignet med deltagerens sædvanlige hagebræt og skulderstøtte. Der blev identificeret forskellige brugervenlighedsproblemer, som kan informere designprocessen af EB eller andre ergonomiske produkter. Derfor kan dette specifikke EB ikke anbefales som værende et bedre alternativ til violinisters sædvanlige ergonomiske hagebræt. Ikke desto mindre er det forsat afgørende at udvikle løsninger, der støtter de enkeltes specifikke behov for at sikre deres tilfredshed. Fremtidige undersøgelser kan udforske andre innovative ergonomiske løsninger, alternative intervention som mikropauser eller inkludering af aktiv og specifik træning under øvning. Desuden er det vigtigt at undersøge og forstå ændringerne i sundhedsadfærd hos violinister og identificere de nødvendige faktorer for at forbedre deres trivsel.

6 Thesis at glance

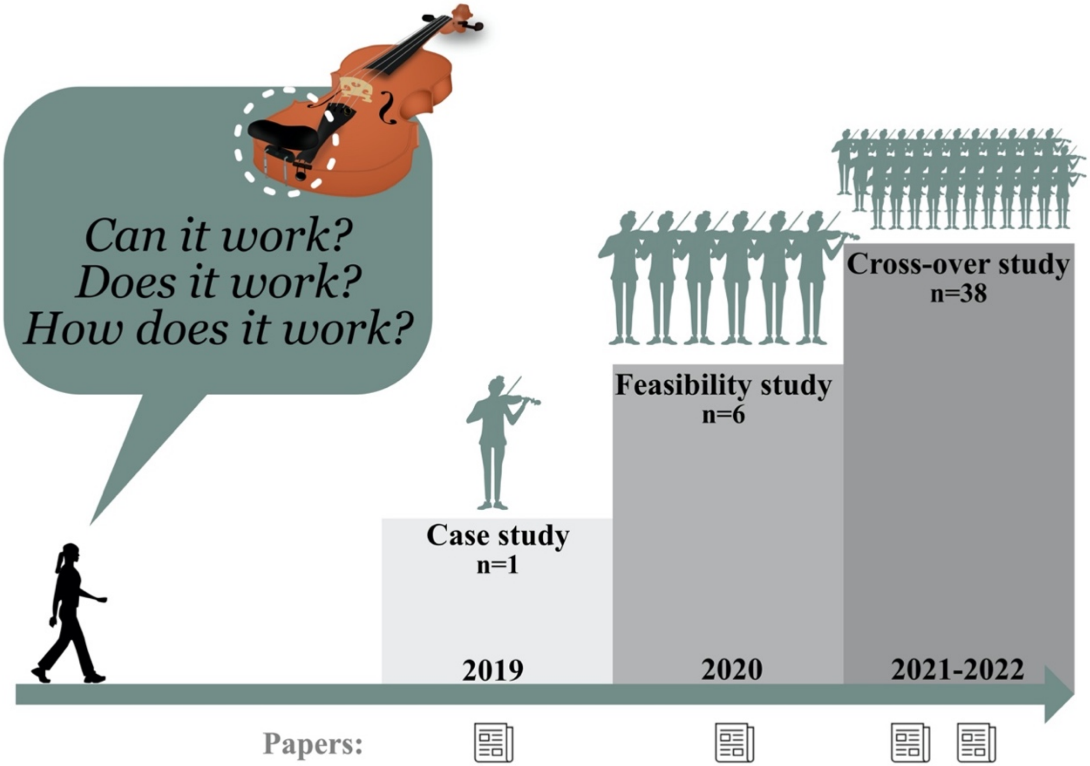


Figure 1 Overview of the Dissertation and Papers

7 Introduction

7.1 Music and classical musicians

Music plays a significant and indispensable role in human life and culture, with the power to profoundly affect our emotions, moods and social connections [1–4]. Music can positively impact physical and mental well-being, contributing to a healthier and happier life [5–7]. Additionally, music has become an integral component of health initiatives to address the needs of an ageing population [8], showing health benefits in treating stroke [9], dementia [10], pain [11], and sleep disorders [12]. Music is a powerful tool that can significantly impact both individuals' and people's overall health [13].

In Denmark, art, including music, is supported by a robust public funding system, with an investment of 28.9 million DK in 2023, highlighting its essential role in Danish culture [14]. Many individuals begin playing an instrument at a young age as a hobby and later pursue it as a profession, becoming integral to their life. In Denmark, music education is paid for by the state, which typically includes a five-year conservatory program that can be extended with soloist education to pursue a professional career [15]. This has resulted in 615 music students completing conservatory education at one of the four conservatories in 2021 [16]

For aspiring musicians, the violin is a popular instrument and holds a significant position in symphony orchestras, with a greater number of violinists and extensive playing time [16]. Playing a musical instrument is a skill that demands extensive dedication and practice. Classical orchestra musicians exemplify this dedication, dedicating 23 to 33 hours per week to playing their instruments. Many of them also engage in teaching or performing in ensembles [17,18].

While listening to or watching musicians play may seem easy and effortless, playing music poses health risks. Both young, untrained and trained classical professional musicians often suffer to pursue their art [19–26]. In the early 1980s, healthcare professionals began to focus on musicians' health. A study published in the Medical Problems of Performing Artists in the United States in 1988 revealed that 76% of classical orchestras/opera musicians suffered from performance-related problems [27]. The incidence of health problems remains high, as shown in the latest systematic review from 2015, where yearly prevalence ranged between 41% and 93%, with a lifetime prevalence ranging between 62% to 93% [21].

Additionally, a Danish cross-sectional study found that professional musicians experience two to three times higher prevalence within a year than the general Danish workforce, and the pain symptoms are more frequent and longer lasting [17]. Most professional musicians will experience playing-related musculoskeletal disorders (PRMD) [28,29], but also amateurs, students from all age groups show a high yearly prevalence of PRMDs ranging from 68-86% [24]. In another cross-sectional study, even 30% of children (n=219) struggled to play their instrument as usual during the last month due to PRMDs [26].

Multiple factors, including physical, mental and environmental conditions, influence musicians' health and development of PRMDs (Figure 2) [30,31]. Therefore, to comprehensively study musicians' work-related strain and health outcomes, it is crucial to consider their overall context [32].
The following section will comprehensively explain the various risk factors musicians encounter throughout their careers.

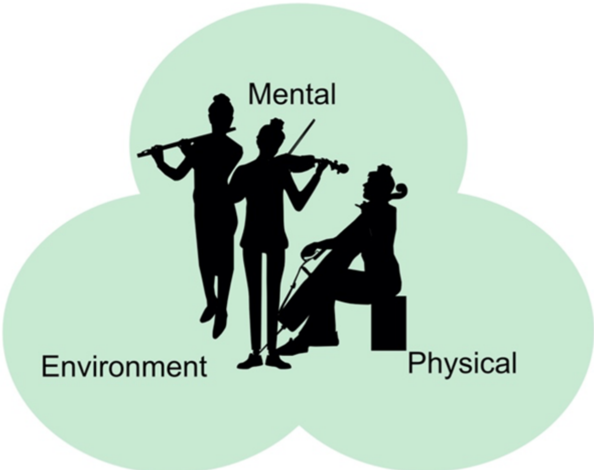


Figure 2 Factors Influencing the Development of Playing-related Musculoskeletal Disorders.

7.2 Risk factors for the development of PRMD

Numerous physical risk factors can contribute to the development of PRMDs. However, there is limited consensus on which specific factor contributes to higher risk [20,33,34]. Classical musicians face a job with high physical demands, including holding an instrument of specific size and shape while maintaining unnaturally asymmetrical static body postures. Playing an instrument often involves prolonged working hours with repetitive and monotonous movements [34,35]. These factors, such as instrument characteristics, body posture and prolonged working hours using static muscle activity, can potentially contribute to the risk of PRMDs [20,36–38]. PRMDs can cause pain, weakness, numbness, tingling, or other symptoms that can interfere with a musician's ability to play their instrument at their accustomed level [39]. If left untreated, PRMD can result in long-lasting or permanent pain and injury, potentially impeding future practice routines or playing abilities [40].

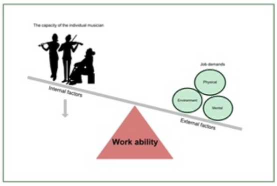
Moreover, a study examining 1353 musicians revealed that two-thirds of the examination outcomes could be classified as PRMD, indicating signs of presumed damage or overuse of tissues subjected to stress exceeding their biological limits [41]. Musculoskeletal disorders in musicians exhibit complexity and involve multiple pathways, often lacking specificity. This means there is usually no clear evidence of a specific diagnosis or a singular root cause of symptoms [42,43]. However, cumulative injuries are a common underlying factor in these disorders [44]. Additionally, musicians often neglect their body's sensory signals due to their extreme dedication to perfecting their performance [45]. Consequently, concealing injuries from colleagues is a common practice among musicians, and playing through pain is not uncommon because musicians do not want to show signs of weakness. This is because the sign or presence of injury can be linked to poor technique, inadequate musical skills, and a lack of physical strength, which could portray them as weak or less talented than other musicians [46].

Furthermore, musicians face a range of environmental and mental stressors that compound these challenges, increasing the risk of PRMD.

Musicians face constant judgment and public exposure, which can lead to performance anxiety [47,48]. They navigate a competitive work environment characterised by high work pressure and the demand for intense concentration [30,49–51]. Additionally, they often work in environments with dim lighting and exposure to high sound levels [51]. Moreover, musicians typically have limited control or influence over the music being played in the orchestra, which impacts their autonomy [50]. The nature of musicians' employment, whether

contracted employees or freelancers, adds to the stress due to job insecurity and irregular working hours, making it challenging to maintain a healthy work-life balance [46].
Given that musicians' identity is closely intertwined with their occupation, to the extent that their instruments become an integral part of their bodies, the development of PRMDs can have devastating consequences [45,52]. PRMDs not only significantly impact musicians' overall well-being [53] but also potentially threaten their careers, potentially forcing them to consider alternative professions or early retirement [21].

In addition to the physical, environmental, and mental factors, internal factors such as individual characteristics also play a role in injury development and have been associated with PRMDs [33,54–56]. Such individual factors include age, biological sex, health behaviour, physical capacity, body composition, and medical history. Characteristics such as age and biological sex, for instance, contribute to the player's physical health profile and capacity. Ageing is a natural process that involves a gradual decline in physiological function observed in most living organisms, resulting in lower individual physical capacity in older people [57,58]. Furthermore, women also show higher pain rates than men [18,22,51,54]. This has not yet been well-established but could be due to, e.g., anthropometrics [59,60], lower physical capacity [61] etc. It is essential to find a natural balance between all these factors (the capacity of the individual) and the job demands (external factors) that have been associated with PRMD [62].
When external loading exceeds the individual's capacity, this can lead to a higher risk of pain, fatigue, reduced productivity, prolonged sickness absence, and premature exit from the labour market [63,64]. This balance between internal and external factors has been described in previous work, and an adaptation of the model is made to illustrate the interplay between external and internal factors (Figure 3) [65].



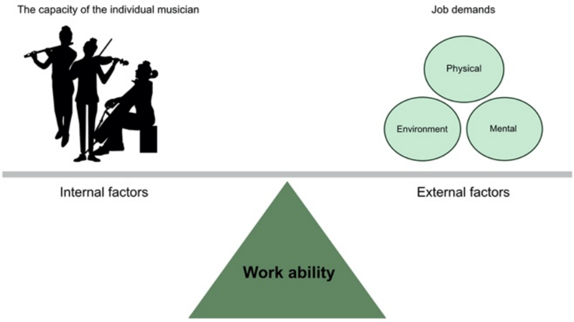


Figure 3 Factors Affecting Balanced Work Ability.
The balance between internal and external factors to have a balanced work ability. Balanced work ability refers to the equilibrium between an individual's internal factors (such as physical and mental health, motivation, and cognitive abilities) and external factors (such as job demands, workplace culture, and available resources), which allows them to effectively perform their job tasks while maintaining their physical and mental well-being [65].

In this dissertation, the focus is on the physical job demands and which changes can be made to get a better balance.

7.3 Job demands among violinists

The most common body areas where musicians report PRMD are the neck and shoulder regions [29,66,67]. In Australia, a report indicates that PRMD is the major contributor to musicians' compensation claims (69.78%). Half of the claims are related to upper body issues resulting from prolonged use of instruments or playing techniques [68]. In general, musculoskeletal conditions are the leading contributors to disability worldwide [69,70]. A Danish report confirms that some of the diseases leading to more use of health care services, extra sick leave and exiting the labour market before the statutory pension age is musculoskeletal disorders such as back pain, neck pain and arthritis [71]. Therefore, it is unsurprising that

PRMD can majorly impact the individual, the workplace and society with increased healthcare costs and lost labour (sick leave or early retirement) [69,72]. These findings in the general population are also supported by a new report from the European Commission on the health and well-being of professional musicians published in 2023 [73].
Specifically, violinists, among all instrumentalists, are often mentioned as experiencing more pain and behavioural changes related to the development of PRMD [17,20,74]. A systematic review found that among string players, PRMD occurs at a higher yearly pain rate ranging from 64.1% to 90%. These rates are particularly high among females [74]. The health consequences of PRMD show its impact on overall health, including disrupted sleep, increased use of painkillers, higher rates of sick leaves and alterations in playing technique. These consequences highlight the distinctive impact on violinists compared to other musicians [17].
Some of the risk factors might be that the violinists adopt a unique working posture, with their body and especially their head turned towards the left to accommodate the positioning of the violin. The violin is held on the left shoulder, balancing the violin body between the left jaw and shoulder. The head is often bent toward the violin to keep it stable. The left hand holds the neck of the violin, with the fingers pressing the strings, while the right arm holds the bow, which is moved over the strings to produce sounds [75–77] (Figure 4). The violin position is often kept for hours during playing, resulting in relatively static and high muscle activity in the upper trapezius. This activity pattern remains constant across different violin repertoires being played [60,78]. The combination of the unnatural head posture and the prolonged elevation of their arms for extended periods sets them apart from other instrumentalists and contributes to a higher incidence of pain in the neck-shoulder area [35,79]. Especially the left side of the upper body, including the neck, shoulders, and temporomandibular joint [74,77,80–82]. The violinists that present pain in their neck and shoulder have been associated with changes in neuromuscular control of the cervical muscles [83].

Figure 4 Traditional Violin Playing Setup and Ergonomic Equipment.
The picture shows the violin, how it is held, and the supportive ergonomic equipment (chinrest and shoulder rest) traditionally used during violin playing.

7.4 The violin is a popular instrument

The violin is a popular instrument for beginners, ranking among the top ten in popularity according to Danish music schools. Around 2993 students played the violin during the 2020-2021 academic year [16]. It is particularly favoured by female players [84]. Denmark is home to seven symphony orchestras, with the violin being the most prominent and prevalent instrument, comprising most of the musicians in each orchestra (Appendix A for an overview of violinists in Denmark) [85].

The violin debuted in the mid-16th century, designed by Andre Amati with a focus on aesthetics and sound [86]. Since then, few modifications have been made to increase the instrument's volume, especially as larger orchestras became popular. The basic design and shape of the violin have remained the same for roughly 500 years because sound is the essential attribute of the instrument [87,88]. The violin is a beautifully constructed wooden box that acts as an amplifier for the vibrations of its four strings. The design of the violin allows it to hang as freely as possible to enable the body to vibrate fully. However, today many violinists use at least one or two pieces of supportive ergonomic equipment attached to the instrument, such as a shoulder rest or chinrest, to improve comfort and play more complex parts with a freer arm [89,90] (Figure 4). The violin is available in different sizes ranging from 1/16 and 1/8 for children to a full-size 4/4 violin for adults. Despite fitting the violin size with supportive ergonomic equipment to the player's body, violinists are exposed to a higher risk of PRMD in the neck and shoulder area [35,77,79,91,92].

Various interventions for violinists, such as strength-training exercises [93–95], kinesio-taping [96], and warming-up exercises [97], have been investigated as potential solutions for preventing PRMD, specifically in the neck and shoulders. However, the effectiveness of these programs remains uncertain due to limited sample sizes and inconsistent research methods, as revealed by a recent systematic review [90].

To prevent pain and discomfort in the shoulders and neck of violinists, an alternative approach is to consider ergonomic solutions [98,99].

7.5 Ergonomic violin solutions

Ergonomics is a scientific discipline that designs and arranges products, systems, and environments to fit the user's needs. One of the key elements of ergonomics in designing and altering musical instruments is accommodating the player's body so that the job task fits the player and not the other way around [100]. This is particularly relevant in the case of the violin, where players need to hold the instrument's weight while adopting a specific posture and movement while playing. By considering factors such as body posture, movement, and physical capabilities, ergonomics optimises the interaction between players and their physical and social surroundings to enhance playing comfort, safety and efficiency [101]. Overall, ergonomics aims to create better systems and products for people by studying the fundamental nature of human interactions with the environment and applying this knowledge to improve individual well-being and system performance [102].

In the profession of a musician, especially for violinists, different ergonomic solutions have been investigated for improving posture and reducing muscle tension and fatigue, especially in the upper body (upper back, neck, shoulders and arms) [103]. These include various types of ergonomic orchestra chairs, some with back support and some without, as well as chairs that are movable or fixed in place [104–107], including the placement in front of the note stand (left or right sitting) [108]. A recent paper has studied a dynamic assistive support used under the left elbow when playing to reduce fatigue in the shoulder muscles [109].

The violin has not been changed much in its appearance due to the production of sound and timbre; therefore, changing the instrument in shape and holding position would require that the traditional and classical environment rethinks the instrument [86]. Accordingly, many adjustable and add-on ergonomic equipment have been developed to make the interface between the violin and player more comfortable. The most common supportive ergonomic equipment for violinists are chinrests and shoulder rests designed to support the violinist's jaw and shoulder, respectively. A systematic review from 2020 found six articles that studied supportive equipment, such as chinrests and shoulder rests, for violinists [103]. Four articles solely examined shoulder rests [110–113], and two focused exclusively on different chinrests combined with different shoulder rests [114,115]. The purpose of these ergonomic solutions is to improve posture by maintaining the stability of the violin between the jaw and left shoulder, alleviate tension and fatigue, and improve comfort during performances. These solutions facilitate more unrestricted movement of the left hand over the strings, enabling the violinist to perform more complex tasks more easily [89,116]. A desirable body position, commonly known as good posture, entails aligning the body to place minimal demand on the neuromuscular system while avoiding excessive strain on bodily tissues [117]. Especially, chinrest, and shoulder rest seek to change the neck alignment of violinists to reduce muscle activity and thereby reduce pain or prevent pain development [98,114]. However, there is no consensus about how to use or not to use these ergonomic products to fit each player's individual needs. Currently, there are no clear guidelines for adjusting these products, and violinists often use trial and error to find a comfortable fit that can align their necks [98].

The following section will describe how ergonomic products such as shoulder rest and chinrest are used.

7.5.1 Shoulder rest and chinrest

The shoulder rest is attached underneath the lower body of the violin, lifting it away from the left shoulder. The use of a shoulder rest is a topic of much debate, particularly regarding its impact on tone production and its benefits in supporting the instrument [118]. However, playing without a shoulder rest means that the left shoulder touches the bottom plate of the violin, which leads advocates of the shoulder rest to argue for its use. Whether or not to use a shoulder rest remains a significant point of discussion among teachers and players, and is a personal preference currently determines its use.

The shoulder rest was developed to address issues stabilising the slippery back of the violin's body, particularly for children with small shoulder widths and women with long necks [119]. Furthermore, the shoulder rest can make the task of the left hand easier by allowing for smoother and lighter shifting techniques without the left hand holding the total weight of the violin. Nowadays, most violinists in Denmark use a shoulder rest as their standard setup for playing. The shoulder rest is now designed to provide a more comfortable contact point with the violin, rather than having the instrument rest directly on or below the collarbone to accommodate different body types and neck lengths. The benefits and freedom of the left arm when playing outweigh concerns about sound loss. A study from 2016 found that violinists should not be afraid that the shoulder rest dampens the sound, but instead, it changes the instrument's sound (the timbre). No single shoulder rest was superior to others when tested with different violins. Each violin required a different setup for the most optimal timbre [87].

Today, most shoulder rests are adjustable in height and width and available in various materials, shapes, and colours. Some violinists prefer to use foam cushions under their violins, also available in different forms, thicknesses, and colours. When searching for shoulder rests, you can find many famous brands, including Kun, Wolf, Viva la Musica, Everest, Pirastro, and more (Appendix B).

The chinrest is attached to the violin's surface between the body and the player's mandible. However, the violin has not always been produced with a chinrest. Playing the violin in the Baroque style means no chinrest is attached to the violin body [120]. It was first introduced in the 19th century by Louis Spohr, who designed a center-mounted chinrest attached to the instrument's endpin. Spohr believed holding the violin with the mandible was necessary to gain freedom in the left hand while moving up and down the fingerboard, especially for more complex music pieces [121]. A discoloration is sometimes still visible on the body of certain violins where the mandible had contact with the violin surface, as the contact can cause varnish stains [121]. Nowadays, many violins are purchased with a chinrest, which can be obtained in different sizes and shapes and attached on top of or next to the tailpiece. The design of a flat black chinrest, which is still commonly used today, is based on the same features as the one created by Louis Spohr.

The shoulder rest's height and adjustment, in general, are often prioritised over the chinrest adjustment, which is reflected in the scientific literature focusing primarily on shoulder rest adjustments [103]. However, two studies from the 1990s investigated the chinrest's effect on either fiddler's neck [115] or pressure and force produced while playing with different chinrests and found that using the Wolf Maestro produced less force and pressure compared to other chinrests (Guarneri and Cliff Johnson) and shoulder rest (Resonans and Playounair Deluxe) [114]. One study from 2020 found that a low shoulder rest was the most comfortable to play with and suggested that a higher chinrest may produce lower workload demands in the left arm and a more aligned head position [111]. However, none of the studies includes time to familiarise with the product before testing or adjusting it to their anthropometrics [103]. Overall, the methodological quality of the studies is inconsistent, and no consensus can be made [103].

While these products are intended to make playing more comfortable and reduce the risk of injury, some players find that they contribute to pain and discomfort and have not changed the overall pain prevalence rates and PRMD found among violinists today [74,80,81]. For example, shoulder rest can put pressure on the collarbone or shoulder. At the same time, a chinrest can cause pain in the jaw and neck muscles due to higher workload demands caused by pressure into the chinrest, including a rotated and lateral bent head position (asymmetric posture). Additionally, some players feel that using these products can interfere with their ability to move freely and affect their performance.

However, no recent studies have investigated whether kinematics or muscle activity changes while playing their instrument using an adjustable chinrest with low shoulder rest compared to their preferred/usual playing setup. Furthermore, investigating the user experience is important to understand violinists' comfort, performance, and potential impact on injury prevention and management. Exploring the potential benefits of using an ergonomic adjustable chinrest could provide valuable insights for optimising playing techniques and promoting musicians' well-being.

7.6 Product evaluation: self-reported and objectively measured

Ergonomic product evaluations often employ objective measures to assess their impact on musculoskeletal function. Some commonly used measures include surface electromyography (EMG), which can detect changes in muscle activity associated with product use [110,112,113] and measure the force required to hold a violin between the jaw and chinrest [111,114]. Another study has incorporated movement sensors of the upper body to capture more comprehensive data on changes using different ergonomic equipment [113]. However, in the mentioned studies, no comparison of the violinist's usual ergonomic setup (their shoulder rest and chinrest) was conducted to investigate the impact on muscle activity and body movements compared to the experimental setup. Therefore, we lack knowledge about the differences and the effectiveness of using their usual playing setup compared to another ergonomic setup.

While objective measures are necessary to test any kinematic or muscle activity changes, they are insufficient to evaluate ergonomic products' subjective effectiveness. They do not capture the subjective experiences of users. User feedback can provide valuable insights into the usability of a product, including factors that might not be captured by objective measures alone. While some violin studies have evaluated user experience based solely on comfort [111,116], there is a lack of in-depth research investigating the overall user experience of ergonomic products among violinists.

The usability of a product, as defined by the International Organization for Standardization (ISO), refers to its ability to help users achieve their goals (effectiveness), the level of resources required for users to complete their tasks (efficiency), and the overall emotional response or attitude of users towards the product (satisfaction) [101]. However, we must expand this definition to fully understand a product's usability. This dissertation will incorporate users' overall experiences with the product, including their self-reported workload demands and design impressions [122]. By including user feedback, we can shed light on design features that promote or hinder usability, and self-reported workload demands can provide insights into the cognitive and physical demands of using a product. We aim to gain a deeper understanding of factors that might influence using an ergonomic product.

Prior to conducting larger trials for a novel product, it is crucial to assess usability issues. Gathering insights from a smaller group of participants helps identify any concerns or obstacles that may impede the intervention's effectiveness, thereby ensuring a comprehensive testing process and significant implications for its success.

7.7 Summary

In summary, PRMD is a significant concern for classical musicians, particularly violinists, who constitute a large proportion of symphony orchestras. Their asymmetrical seating posture and prolonged, repetitive work with high static muscle activity make them particularly vulnerable to these disorders. These disorders can significantly impact their careers by affecting their playing ability and limiting their opportunities. Furthermore, this burden not only impacts individuals but also places a strain on society, leading to higher healthcare expenses and reduced productivity.

To alleviate discomfort, many violinists use supportive ergonomic equipment such as chinrests and shoulder rests to improve the interface between the violin and the player. However, despite the widespread use of such equipment, studies have shown that many violinists continue to experience pain even when using them. Additionally, there is no consensus on these products' proper usage or adjustment. The ergonomics field regarding violinists' products remains under-researched, leading to a lack of understanding regarding the effectiveness of such products in altering muscle activity and improving upper body alignment. Moreover, there is little comprehension of how violinists perceive these products' effectiveness and usability. Therefore, it is essential to investigate this research area further to understand better the potential benefits and drawbacks of utilising an ergonomic product for violinists.

8 Aims

This PhD dissertation aimed to investigate the feasibility and user experience of using a selected novel ergonomic chinrest among professional violinists. Furthermore, it aimed to compare the biomechanical working conditions of the novel chinrest with the violinists' usual ergonomic equipment, thereby exploring potential improvements for their health and playing conditions.

The specific aims were:

Study I:

- To investigate the preliminary feasibility and acceptability of using an ergonomic chinrest with a low shoulder rest in a professional high-string player without PRMD for six weeks. Secondary to register newly developed pain and fatigue.

Study II:

- To assess the feasibility of playing the violin with the ergonomic chinrest with or without a low shoulder rest, evaluated in terms of compliance, adherence and usability over a two-week familiarisation period.

Study III:

- To investigate and compare upper body kinematics and muscle activation patterns during violin playing between a usual chin and shoulder rest and an ergonomic adjustable chinrest and low shoulder rest.

- To explore the user experience of violinists who used the novel ergonomic chinrest with a low shoulder rest for two weeks. Through that experience, we wanted to learn about the potential user barriers and facilitators related to their motivation, usage behaviour, usability, and acceptability when trying a new product.

9 Structure of the Dissertation

In this Dissertation, the different studies represent different papers as follows: Study I (Paper I), Study II (Paper II), and Study III (Papers III and IV) due to their different designs and methodologies. Study I-III results will generally be summarised with key findings; however, the different Papers I-IV are included at the end of this dissertation containing more detailed descriptions.

A case study (Study I) was conducted as a proof of concept to establish a foundation for the larger studies. Each Study is described separately with methods and results.
Identical methods used across Study II and III are described once, and the changes made are highlighted in Study III; this is done since the implication of changes and additional measured outcomes are few in Study III.
The outcomes of Study I informed the specific methodology of Study II. Likewise, the outcome of Study II had specific implications for the design of Study III. The specific implications (methodological considerations) are described in the methods section after each study to make the process between each conducted study transparent.
In the end, an overview and summarising section of the outcome measures and results for all studies (I-III) are presented.

Before outlining the methodology and results, a comprehensive systematic online search was conducted to identify an adjustable ergonomic chinrest. This online search section is presented prior to Study I. The following section will give an overview of the methods across Study I-III.

10 Overview of Methods across Studies I-III

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This section will give an overview of the different study methods presented in this dissertation, followed by the ethics and timeline for all studies. Table 1 displays the different methods used across each Study I-III.

Table 1 An Overview of Studies, Associated Papers, and Study Designs.

Study	Paper	Year[1]	Design	Sample (n)	Data collection: Subjective	Data collection: Objective
I	I	2019	Case study	1	Questionnaires[2]	RULA
II	II	2020	Feasibility study	6	Questionnaires[2]	ViMove EMG
III	III and IV	2021-2022	Cross-over design and exploration of the user experience	38	Questionnaires[2]	Vicon EMG Sound

[1]= is the year the study was conducted. [2]= self-developed questionnaires. RULA: Rapid Upper Limb assessment tool is a survey method to investigate work-related disorders in the upper limb. ViMove and Vicon: motion capture products to monitor body movements objectively. EMG: Electromyography to measure muscle activity.

10.1 Ethics

The project descriptions for all three studies (I-III) were approved, including the management and storage of personal data in the office of the Research and Innovation Organization of the University of Southern Denmark (Study I: 10.202, Study II: 10.990, and Study III: 11.422). The Regional Scientific Ethics Committee for the Regions of Southern Denmark assessed the procedures for each study, and no approval was required for these specific types of studies (reference number Study I: 20182000-90, Study II and III: 20202000-87).

All participants provided written consent per the Declaration of Helsinki before the study started for Study I-III. Study II and III were retrospectively registered at ClinicalTrials.gov under the identifier: NCT05509465 and NCT05604313, respectively [123].

10.2 Timeline: Implications of Covid-19

This PhD project was influenced by the global Covid-19 pandemic, which affected two out of the three years of the project. The PhD started in December 2019, with the first lockdown and multiple restrictions implemented in March 2020. These restrictions significantly impacted Studies II and III's recruitment processes and testing periods. Study II was affected because there were only a few months available for laboratory testing during the summer and early autumn of 2020 before another lockdown was enforced, making further recruitment and data collection impossible. Study III was postponed from the beginning of January 2021 to the beginning of August due to National and university restrictions and the researcher's sick leave. The recruitment for Study III was also affected by the Covid-19 pandemic. Many participants had initially agreed to participate in early 2021, as they had extra time in their calendars due to not being allowed to play in their orchestras because of National restrictions. However, because the project could not start, many of the recruited participants dropped out when the project started due to overwhelming work schedules, and some of the participants were injured or on sick leave during the new recruitment period.

11 A systematic online search for ergonomic chinrest

Based on the scientific literature that emphasises the benefits of a higher chinrest and a lower shoulder rest [111], an extensive systematic search on the Internet to find an ergonomic chinrest was conducted in 2020. Firstly, I wanted to find a moveable chinrest; however, that was not possible. Therefore, the new aim was to find a single product incorporating all the necessary features to achieve the desired adjustments accommodating an aligned head posture that considers the player's anthropometrics and playing style.

As the primary author (SM), I searched 13 recommended webpages[1] for chinrests and conducted a Google search using the terms "adjustable chinrest", "ergonomic chinrest", "chinrest", or "violin chinrest" to find other webpages selling ergonomic equipment for violinists. After searching, 25 brands with 92 different models were found. Of these models, 79 cannot be adjusted in the single product in itself, while eight have only one adjustable function. Two models from Wittner and Musanus have two adjustable functions, allowing for changes in both height and tilt. Additionally, two models (Kréddle and Viva la Musica) have three or more adjustments in the single product. See Table 2 and Appendix C for more information and details about the chinrests found.

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[1] Shar Music (https://www.sharmusic.com/), Thomann (https://www.thomann.de/), Fiddlershop (https://fiddlershop.com/), Johnson String Instrument (https://www.johnsonstring.com/), Violin Pros (https://www.violinpros.com/), StringWorks (https://www.stringworks.com/), The Violin Shop (https://www.theviolin-shop.com/), Southwest Strings (https://www.swstrings.com/), The Sound Post (https://www.thesoundpost.com/), Gear4music (https://www.gear4music.se/), Danguitar, Denmark (https://www.danguitar.dk/), Hertzmusik (https://www.hertzmusic.dk) and Musikinstrumenter (https://musikinstrumenter.net/)

Table 2 The different chinrests with adjustable features.

Brandname and model	One adjustable function	Two adjustable functions	Three or more adjustable functions
Wolf 1. Maestro model 2. Special model 3. Classic model 4. Maestrino model	Height		
Dolfinos	Height		
Flesch 1. Height adjustable	Height		
Adjustable Pitch	Pitch		
SAS	Tilt		
Wittner: 1. Augsburg model 2. Zuerich model		Height and Tilt	
Viva la Musica			Height (Three heights from 34 to 42mm) Tilt Pitch Rotation One top for the jaw
Musanus		Height and tilt	
Kréddle			Height (Four heights from 28 to 45mm) Tilt, Pitch Rotation and Placement Two tops for different jaws

Figure 5 The Adjustable Ergonomic Kréddle Chinrest. The Kréddle chinrest was the chosen ergonomic chinrest used without shoulder rest (I) or with a low shoulder rest (II and VI). Picture III, IV and V shows the different adjustments that can be made using Kréddle. V: shows the height adjustement and III show the different tops that can be selected.

Due to more adjustability and flexibility, the Kréddle chinrest (Kréddle®, Wyoming, US) was chosen as the ergonomic chinrest (EC) to be tested [124] (Figure 5). Kréddle can be tailored to fit a player's arm and neck length and playing style, which may result in less muscle activity in the neck and shoulders as there is no need to press the jaw down to stabilise the violin. This can help keep the head more aligned/in the middle. The Kréddle is designed to be played without a shoulder rest, but the owner claims it can also be played with a low shoulder rest. The whole idea behind Kréddle is to have collarbone contact with the violin while keeping an aligned head position. Thereby not affecting the tone of the instrument. The Kun shoulder rest is well known (Appendix B) and was chosen as the shoulder rest.

12 Study I

Study I aimed to investigate the preliminary feasibility and acceptability of using an ergonomic chinrest with a low shoulder rest in a professional high-string player without PRMD for six weeks. Secondary to register newly developed pain and fatigue.

12.1 Methods

Study I is a case report following the case-report guidelines (CARE) [125]. The investigation started in January 2019 and ended in the middle of April 2019.

12.1.1 Selection of a case

Considering the scarcity of professional violinists in Denmark, which amounts to only 179 violinists (as per Appendix A) and taking into account the need for participants in the upcoming studies, I decided to recruit one viola player.

In this case study, the aim was to assess a string player who lacked expertise or prior knowledge in replacing or using a chinrest other than one similar to that developed by Louis Spohr. This criterion aimed to represent the experiences of a typical Danish player who has only replaced their shoulder rest and purchased an instrument with an already-attached chinrest. The case was recruited through word of mouth and networking with the researcher's acquaintances.

12.1.2 Intervention and data collection

A six-week trial period was given to the case with the information about playing most of the time with the EC. Before the trial period, the case attended an introduction meeting in the researcher’s private home (SM). Information about how to use and attach EC was provided during the meeting, along with nine YouTube instruction videos [126] and information sheets [124] from the EC company. Furthermore, information about head alignment was given about not tilting the head laterally or having the head rotated for long periods. An objective assessment of the player's body posture was conducted during the introduction meeting. Subjective feedback was collected at the end of each trial week, where participants were asked to complete a questionnaire. Below is an overview of the observation tool used as the objective outcome and the questions included in the questionnaire for subjective outcomes.

Objective outcome

Before the trial period and before and after attaching the EC, the following objective measurement tool was used to assess the case body posture (rated through observation).
The accessible objective measurement tool, the Rapid Upper Limb Assessment (RULA), was used to evaluate the case body posture. It is an easy and cost-effective tool, established to be reliable and validated for work-related upper limb ergonomics [127]. A score is assigned for each body part: upper arms, forearms, wrist, neck, trunk and legs, including additional scoring for the work done (static, repetitive or forced/loaded posture). A grand score is then provided based on all the different scores ranging from 1- ≥7 and with different recommendations about the work posture. A Grand score between 1-2 is considered acceptable, while scores of 3-4 indicate a need for further investigation, with potential changes required to the work posture. Scores of 5-6 suggest the need for a more in-depth analysis of the work posture and changes that should be implemented soon. In contrast, scores of 7 or higher indicate an immediate need for changes and investigation. A picture from the original worksheet for scoring the neck posture can be seen in Figure 6.
The case chose to play a self-chosen piece (five minutes playing) with the usual chinrest and shoulder rest and then play again after attaching the EC with a low shoulder rest.

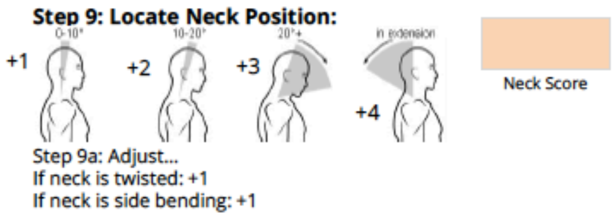


Figure 6 The worksheet from the Rapid Upper Limb Assessment (RULA). This selected part of the RULA scoring shows the scoring of the neck posture.

During the trial period, subjective outcomes (rated by the subject) were used to gather information about the usage, preliminary usability (performance and comfort) and secondary problems (pain and fatigue).

Subjective outcomes

At the end of each week, all subjective outcomes were answered in a paper questionnaire.

Usage behaviour

Compliance was measured if the case used the EC or not. The case was asked, *"How much have you played with EC out of total playing time in the last seven days".* Answers were given from 0% (no use), 1-24%, 25-49%, 50-74%, 75-99% and 100%. Full EC compliance was defined as 75-99% or 100% in any of the weeks.
Furthermore, hours played per week during the trial were given.

Performance and comfort

Two questions were constructed for this case with inspiration from another study measuring comfort when trying another chinrest and scored from 1 (very good), 3 (neutral) to 5 (very poor) [114]. In this study, we constructed the below questions.
The performance question: "*Does the chinrest affect how you play in a positive or negative direction"* and the comfort question: *Do you feel a difference in how you hold your instrument in a positive or negative direction?* A 5-point Likert scale was used (1 positive, 3 neutral and 5 negative).

Acceptability

The case was also asked if she preferred her own chinrest compared to Kréddle by answering *"Yes", "No",* or *"Don't know"*. A self-constructed question that was developed to indicate if the participant would consider changing and if she liked the product.

Pain intensity and fatigue

Assessment of pain and fatigue intensity in the neck and upper back in the last seven days was rated using an 11-point numeric pain rating scale (NRS ranging from 0=no pain/fatigue at all to 10=worst imaginary pain/ worst possible fatigue). The Nordic Musculoskeletal Questionnaire, which has been validated for pain assessment, was used [128]. The NRS chosen for measuring fatigue is an assessment tool that is simple to understand, quick to complete, and easy to score. It also has minimal associated expenses due to its replicability. It has been tested to be valid and reliable [129,130].

12.2 Results

A 32-year-old female viola player participated in Study I. The instructions for using the EC were not feasible in its current form of YouTube videos and material from the webpage. After reading the information and watching the videos, the case expressed that more help was needed to figure out how to attach the product. Based on the feedback and observation that the case failed to assemble the EC, the researcher decided to plan a one-hour video call with the product developer, which successfully helped with how to install and use the product. The baseline scoring of RULA indicated a risk of developing musculoskeletal disorders using her usual setup (score of 5-6).
However, only the partial scoring of the neck posture changed by one point, but the overall score remained the same for using EC (score of 5-6). It was feasible to use EC, and the case complied fully with using EC for five out of six weeks. However, existing baseline pain was an obstacle that made her interrupt playing with EC for one first trial, and she waited until she was pain-free to play again and played all six weeks. However, pain and fatigue increased initially, and performance and comfort scores were also influenced negatively. In the end, it changed; no pain or fatigue was reported, and the performance and comfort level were respectively scored neutral and positive (Figure 7). Furthermore, the case did not know if she preferred her usual setup over EC, which could indicate acceptance towards using the product.

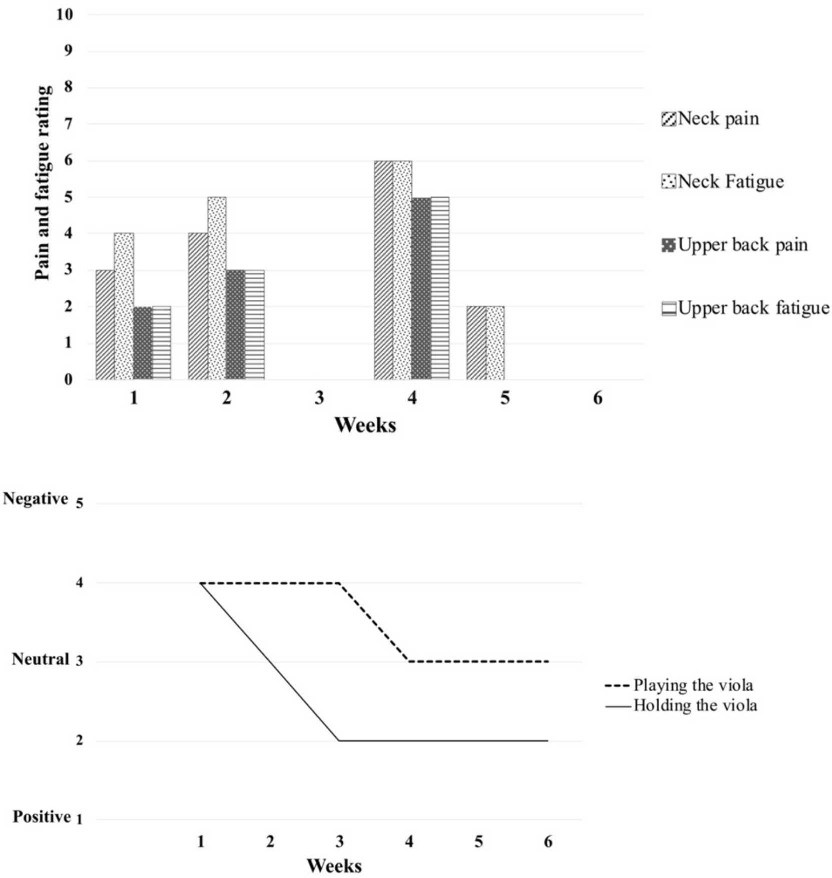


Figure 7 Impact of Violin Playing, Holding, Pain and Fatigue in Study I. These two figures present the pain and fatigue ratings over a six-week duration, highlighting their impact on violin playing and holding. The case forgot to rate pain and fatigue in week six.

12.3 Implication for Study II

Based on the results and experiences from Study I, some methodological alterations were made prior to initiating Study II. The implications for Study II are listed below.

12.3.1 The instructions

In this case study, the instructions on assembling and using the product were only successfully given through a 1-hour video call with the product owner, which is quite a long time for instructions and can be problematic because the product owner is involved and can influence the outcomes. Therefore, based on the information in the video call, we planned to create shorter introduction videos for the following study. Making the videos easy to understand regarding adjusting and using the EC is essential. These videos were created by the primary author (SM) and were incorporating elements from the YouTube videos [126] and information sheet from the EC company [124].

12.3.2 Self-reported questions

The self-reported questions on performance and comfort were inspired by earlier published research in this area [114] and my knowledge about the topic. Although it appears that participants understood the questions, we cannot be certain that they measured what we intended since they have not been validated or tested for reliability. Therefore, we planned to base the questions on more validated and reliable questionnaires for the following study. Answering the questionnaire only once a week and retrospectively can lead to recall bias, which is unavoidable [131]. Moreover, the case may have forgotten to answer the questions in Study I because she was only asked once a week. As a result, we did not obtain a precise or detailed overview of hours spent using the EC. Therefore, in Study II, we planned to measure playing hours every day, whether using the EC or not. To ensure commitment and minimise forgetfulness, we planned to conduct a motivational phone call with reminder text messages from the primary author (SM) every day in the evening.

12.3.3 Trial period

We had some methodological considerations regarding the trial period of six weeks. While it is long enough for a habit change [132] in the following Study II, we were more interested in a familiarisation period with the EC. This would provide enough time for participants to try it out, adjust to it, and consider using it in the future. However, we had to consider that an extended trial period may result in a high dropout rate. Therefore, we planned to shorten the trial period to a two-week familiarisation period to strike a balance between gathering valuable insights about the product and minimising the burden on participants. Furthermore, a study found that participants who play on different violins immediately struggle to adapt to the different configurations, resulting in less precision and fluency than their own violin [133]. Therefore, a two-week familiarisation period may give them enough time to get used to the new setup.

12.3.4 Participants

In Study I, the case presents an increase in pain over the trial period, and based on that case experience, we wanted only to include pain-free and non-injured participants because there could be a higher dropout rate, as adding more pain to already existing pain. Furthermore, participants with injury or pain have been shown to have different muscular activity patterns than non-injured/pain-free musicians [134,135].

12.3.5 Objective measures

The following study was planned at the university. Although RULA provides a quick and cost-effective assessment of the load on the musculoskeletal system, it is only somewhat reliable because it is based on subjectivity. A study found that trained and skilled physiotherapists observing and rating 30 violinists' postures varied widely, with inter-rater reliability scores ranging from poor to fair [136]. For study II, we used methods that give a more precise and accurate estimate of the violinists' working posture (body movements and muscle activity).

In summary, the implications for Study II were to create shorter introduction videos, use more validated and reliable questionnaires, measure playing hours every day, shorten the trial period, and use methods that can provide a more accurate estimate of the violinists' working posture.

13 Study II

Study II aimed to assess the feasibility of playing the violin with the ergonomic chinrest with or without a low shoulder rest, evaluated in terms of compliance, adherence, usability, and acceptability over a two-week familiarisation period.

13.1 Methods

The design of this study was a one-arm feasibility study following the CONSORT 2010 extension for pilot and feasibility trials [137]. We used the template for intervention description and replication (TIDieR) to facilitate a thorough description of the familiarisation period [138]. We made a quick literature search on existing literature on ergonomic products to ensure we initiated a meaningful study that had not been conducted before. The investigation started in August 2020 and ended at the beginning of October 2020.

13.1.1 Study sample

The study recruited fluent Danish or English-speaking violinists aged 18 or older who could play the classical protocol repertoire [60]. Eligibility criteria required that participants reported no severe pain symptoms in their neck or upper extremities, rated as three or lower on a numeric rating scale ranging from 0 to 10 (worst imaginary pain).

Exclusion criteria included recent trauma to the upper cervical spine or upper extremities within the last year, a previous or planned shoulder/neck operation, life-threatening health disorders, a pacemaker, or severe eczema on the neck and upper extremities. To ensure adequate recruitment for Study III, violinists with a permanent contract in a Danish symphony orchestra were also excluded from this study.

The study enrolled individuals through social media and from a nearby music conservatory.

13.1.2 Intervention

A 14-day familiarisation period was given to the participant to adjust and play with EC. They were given the information about having equal daily playing time with EC with and

without a low shoulder rest (SR and WSR). The low shoulder rest was chosen to be the Kun Super shoulder rest because it can be set and adjusted to a low height.
The information was given through three short videos, including an overall introduction to the project, focusing on keeping the head aligned and two instructional videos about assembly, adjusting the EC, and keeping the shoulder rest in the lowest setting [139,140].
To boost compliance, the participants received a short text message (SMS) on their phone to fill in a paper diary every day, and a motivational phone call was made after the first week. If a violinist couldn't use EC continuously for more than five days during the familiarisation period due to illness or interruptions, the period was extended by seven days.

After the familiarisation period, a test day was conducted in the laboratory using a balanced crossover design to compare different playing conditions for the violin with the identified EC. The three conditions tested were: 1) playing the violin with SR, 2) playing the violin WSR, and 3) playing the violin with the individual musician's usual chinrest and shoulder rest (UC). Scales were done as a warm-up (A and E major scale in four different speeds) followed by an excerpt of a music piece played for 76s (second movement from W. A. Mozart’s violin concerto no. 5 in A major) followed by a metronome set to crotchet = 60 beats per minute. For two weeks, the participant had the chance to practice the notes.
In Study II, this last part explored the variations in lateral head posture with different chinrest and shoulder rest conditions. It enabled a statistical power calculation for a larger-scale evaluation trial to assess the effect of EC on head kinematics.

13.1.3 Data collection

A web-based questionnaire was employed as a starting point to evaluate the participants' motivation to take part in the study. Moreover, the questionnaire included baseline demographics such as age, biological sex, height, weight, prior familiarity with ergonomic equipment, age at which they started playing their main instrument and playing habits. The violinist kept a record in a paper diary every day of playing hours, their confidence level, adjustment, and emotions concerning using the EC. The follow-up questionnaire was self-reported queries on sound quality, comfort level, and performance level. Figure 8 shows the overview of the data collection, including the test day.

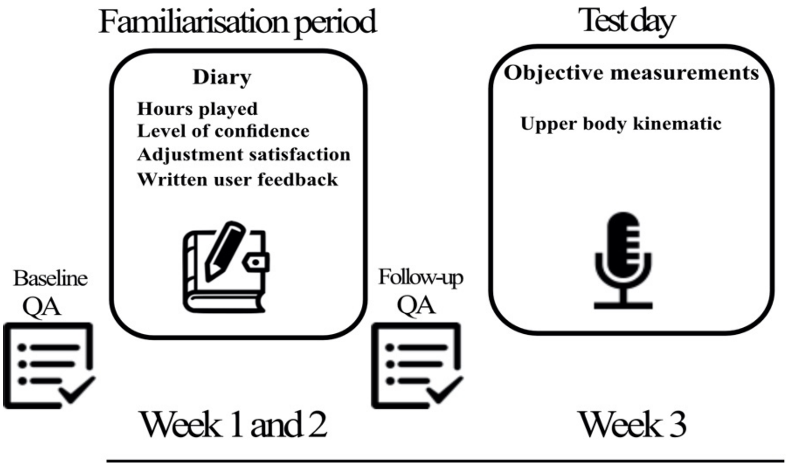


Figure 8 Overview of the data collection in Study II. The secondary aim measuring upper body kinematic was done during the test day. QA= questionnaire.

Subjective outcomes

Motivation

One question was used to assess the motivation of the violinists to participate: *"Can you elaborate on why you want to try a new chinrest?"* This question was not based on a specific theoretical framework.

Usage behaviour

The number of days the violinist played under different conditions (SR, WSR, or usual) during the two weeks was used to measure adherence. Each condition (SR and WSR) had to account for at least 25% of the total playing time to meet the compliance criterion. A condition was considered a favourite if compliance exceeded 50% for SR or WSR.

Usability

The usability outcomes were divided into effectiveness, efficiency, and satisfaction as defined in the ISO standard [101].

Effectiveness

Three outcomes were assessed in this study to measure effectiveness: confidence level (a measure of success in using Kréddle to achieve a specific playing goal), instruction comprehensibility and performance score. All questions were developed specifically for this study. The question for confidence was as follows: *"How confident do you feel when playing with Kréddle? A reply as 'very confident' on the rating scale indicates that, after several days of use, you can still play the scales and piece of music provided."* A 5-point Likert scale was used to rate confidence, with five indicating *"very confident"* and one indicating *"not very confident".*

To test instruction comprehensibility, participants were asked: *"Before you started using Kréddle, did you receive enough information to feel well-equipped to use it?"* Participants could respond *"yes," "no,"* or *"don't know".*

For the performance questions, we drew inspiration from the extended version of the Quick Dash questionnaire, which consists of four items for performing artists related to work disabilities/symptoms [141]. We were inspired to use the same validated and reliable scoring system used in Quick Dash, and therefore, we made questions that had to be scored on a 5-point Likert scale [141]. The performance questions options range from *"no problem"* (score 1) to *"impossible"* (score 5). See how the score was calculated under the Comfort section on the next page, and see Table 3 for the specific question.

Efficiency

To measure efficiency, we developed a specific question for this study framed like this: *"Have you found an adjustment of Kréddle that is working for you?"* and could be answered by *"yes", "no",* or *"not yet".*

Satisfaction

Satisfaction was assessed through various measures, including comfort levels when using the EC with SR or WSR. The assessment also involved asking specific questions about sound and collecting subjective feedback on the overall experience using EC (qualitative written data on the participants' emotions towards EC).

Comfort

We drew inspiration from an earlier study that tested comfort using questions about the chinrest, including position, curvature, size, height, etc. [116]. We created self-reported questions about comfort. Here we also used the same validated and reliable scoring system used in Quick Dash, and therefore, we made questions that had to be scored on a 5-point Likert scale [141]. The comfort questions options range from *"very comfortable"* (score 1) to *"very uncomfortable"* (score 5).

See the list in Table 3 of the different questions below for performance and comfort. The questions were asked for both SR and WSR.

Table 3 Overview of Specific Questions for Performance and Comfort Scores. This table lists the questions that provide an overall performance and comfort score.

Questions	Performance	Questions	Comfort
Question 1	*"Have you had difficulty playing your violin?"*	Question 1	*"How comfortable was playing with SR/WSR in the last 14 days?"*
Question 2	*"Have you had difficulty using your normal technique when playing?"*	Question 2	*"How comfortable was the height of the chinrest (with your chosen adjustment)?"*
Question 3	*"Have you had difficulty playing as well as you would like to?"*	Question 3	*"How comfortable was the configuration of EC that you have chosen?"*
		Question 4	*"How comfortable was the size of the chin plate of EC?"*

		Question 5	*"How comfortable was the EC surface against your skin?"*

SR: shoulder rest when using the ergonomic chinrest, WSR: without a shoulder rest when using the ergonomic chinrest. EC: ergonomic chinrest

An overall score is based on the answers given in each question by simply adding the assigned values for each response and dividing it by the number of questions (three questions for performance and five for comfort). Then subtract one and multiply by 25 to obtain a score out of 100. The overall score is calculated below, and a higher score indicates a negative or reduced playing performance or comfort.

$(\frac{Sum\ of\ responses}{total\ number\ of\ questions} - 1)$ x 25 = a score out of 0-100.

Sound

In the follow-up questionnaire before the test day, the violinists had to evaluate the tone and overall sound experience using SR and WSR by scoring it on a 5-point Likert scale from “very good” to “very poor”. These questions were adapted for this study from a previous investigation into factors that influence the quality of violin performance [142]. The questionnaire asked: *“How was the tone during your violin performance when using Kréddle with/without a shoulder rest in the last 14 days?*” and *“How was the overall sound when using Kréddle compared to your usual setup in the last 14 days?”* The violinists answered these questions for both SR and WSR setups.

Emotions

The violinist was asked to write their daily experiences using SR or WSR in the diary. Two developed questions were provided: *"What are your immediate reactions using Kréddle? It can be about how the adjustment works for you with Kréddle, how you find the usage of Kréddle or general thoughts. Both positive and negative descriptions are considered valuable for the project.”* The second question was, *"If you have not used Kréddle, then just write why not?”*

Objective outcomes

ViMove

In Study II, the ViMove system was used as a measurement tool to track neck movements using two wireless movement sensors: one placed on a hairband over the skull and the other placed above and on the skin of T3 (Figure 9). The system has been validated and has shown clinically acceptable agreement when compared with the Vicon motion capture system for measuring neck positions [143]. The ViMove software analyses the data and calculates the angles of the upper and lower sensors separately relative to the line of gravity. The ViMove software automatically calculates the lateral head flexion angle, which was the focus of Study II.

Figure 9 Placement of the ViMove sensors. One was placed on a hairband and another over T3 on the skin.

Anthropometric measurements

Height and weight were done on the test day using a wall ruler and a Tanita weight. The body mass index was calculated and divided into overweight ≥25 kg/m^2 and normal weight between 18.5-24.9 kg/m^2.

13.1.4 Data analysis

Quantitative data

Statistics were performed in STATA (StataCorp, version 17). The descriptive statistics are reported as either means (standard deviation, SD) or medians (interquartile range, Q1-Q3).

The normality assumption was evaluated through the Shapiro-Wilk test, histograms, and QQ plots. Results indicated a non-normal distribution. The Wilcoxon signed-rank test was done to compare compliance, confidence, adjustment, performance, and comfort scores between the two groups: SR and WSR. Specifically, a score of 100 was assigned to participants who did not report any adjustment or gain in confidence within the two weeks for adjustment and confidence variables, respectively. The threshold for statistical significance was established at $p<0.05$.

The study did not involve a formal sample size calculation. Instead, a sample size of 10-12 was set as a general guideline for a pilot or feasibility study at the beginning of the research [144].

The lateral head angle was first evaluated by dividing the angles into two categories: neutral (below 10 degrees to either the left or right side) and awkward (above 10 degrees to either the left or right side) [145]. The working time spent in these two categories was calculated in percentage and used to evaluate SR, WSR and UC (Figure 10). Even though this is a feasibility study, we made a preliminary effective test to determine any differences between the setups using the Kruskal-Wallis H test and making an amplitude probability distribution function (APDF) on the head angles to identify the static, median and peak levels.

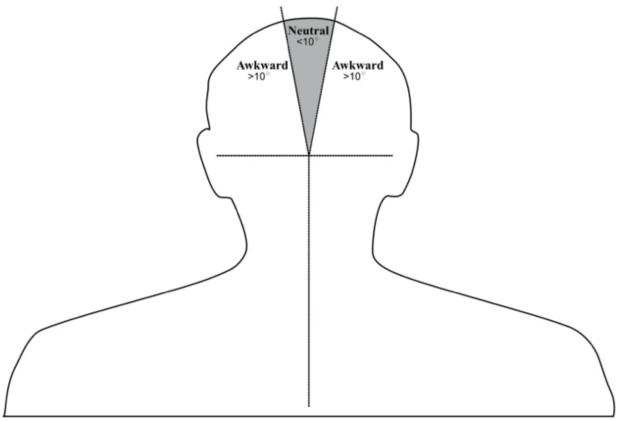


Figure 10 Awkward head position. The head position was calculated between being in neutral and awkward head position.

Qualitative data

Content analysis was performed on the open-ended responses from the diary and QA to condense the raw data into global themes [146]. The responses were coded in their original language, and the primary author reviewed them independently and repeatedly to understand the data better. Subsequently, the themes were classified into positive, negative, and general categories and condensed further into global themes.

13.2 Results

13.2.1 Recruitment, participants and motivation

Due to Covid-19 restrictions described in section 10.02, the number of eligible and included participants fell short of our intended range of 10-12 individuals, a rule of thumb for pilot and feasibility studies [144]. In total, six participants were recruited over five days, consisting of two professional violinists (one freelance and one teacher), two conservatory students, and two amateur violinists.

This recruited sample comprised three men and three women with a mean age of 35 years old (SD 9).

The violinists expressed a range of motivations for their participation in the project, including curiosity, the pursuit of a better chinrest, the desire for improved posture, and one individual's aspiration to play without a shoulder rest.

13.2.2 Feasibility outcomes

Study II showed that compliance WSR was significantly less than for using SR (p=0.04). For two participants, the compliance criteria of using each setup at least 25% of total playing time were not met playing with SR. However, the adherence was high (days playing with EC), as seen in Table 4. The instructions were rated sufficient for all six participants. When participants used WSR, we found a significantly longer time gaining confidence (p=0.03) than SR. This difference was observed because two participants using WSR did not achieve confidence within the two weeks. Additionally, using WSR had a lower performance score (p=0.03) than using SR.

Furthermore, more negative comments were noted about using WSR than SR, which were generally about pain and playing problems.

SR showed, in general, high compliance and usability compared to WSR. SR was more feasible than WSR due to its higher performance score, more playing hours, and faster confidence. Based on these results, EC would only be tested using SR in Study III.

Table 4 Overview of the feasibility results in Study II.

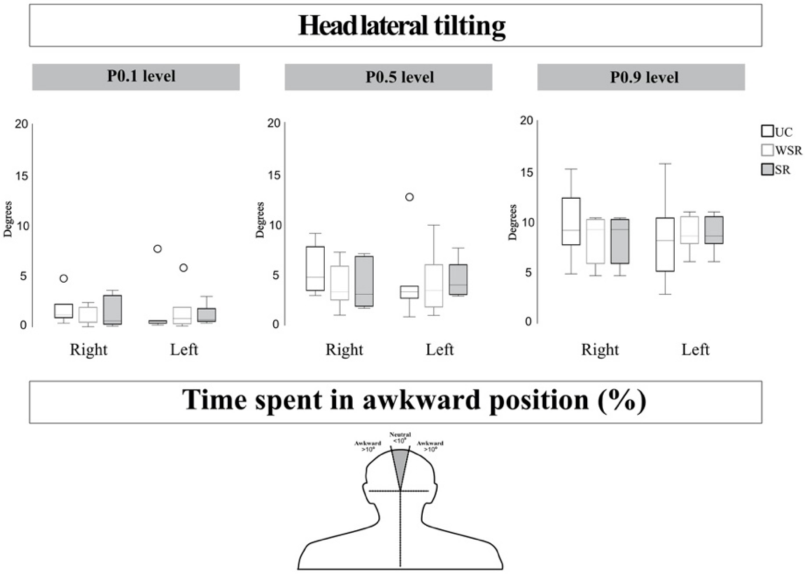
Variable	**Study II (n=6)**
Familirasation period	
Total playing hours during the 14 days, median (IQR)	22.6 (14.1)
Adherence (%), median (IQR)	89.3 (12.5)
	WSR/SR
Compliance (%), median (IQR)*	45.1 / 54.9 (18.8) / (18.8)
Usability	
	WSR/SR
Instructions comprehensiveness (yes/no) (n)	6/0
Confident* (days), median	6 / 5
Performance*, median (IQR)	58.3/ 45.8 (25) / (25)
Adjustment (days), median	6 / 1.5♦
Comfort, median (IQR)	40 / 30 (25) / (40)
Sound 1. Overall sound 2. Tone	No difference found
Emotions	
Negative comments, number (total)	26/3 (29)
Positive comments, number (total)	7/12 (19)

* Indicate a significant difference between WSR (playing without shoulder rest) and SR (playing with shoulder rest). ♦One never found an adjustment. IQR: Interquartile range

13.2.3 Objective outcome

Objective data on head kinematics were obtained to enable a statistical power calculation for Study III and to explore the effect of playing with the different conditions.

Figure 11 provides an overview of head kinematics in Study II. The figure shows an APDF of the head angles, followed by the percentage of time spent in either a neutral or awkward lateral flexion head angle during work. The figure shows no significant difference for all conditions (UC, SR and WSR) with the head tilting angle at the P0.1 level under 4°, the P0.5 level around 4-5° and the P0.9 level around 10°. Furthermore, no difference was found between time spent in the awkward position and the different conditions. Additionally, we found that half of the participants increased their time spent in the awkward head position using SR, while the other haft showed a decrease.



	UC	WSR	SR
Median (IQR)	15 (26)	8.5 (13)	8.5 (4)

Figure 11 Overview of the head kinematic results in Study II. The lateral tilting angle is displayed in the Amplitude probability distribution function from static (p0.1), median (p0.5) and peak level (p0.9) and also displayed and categorised into two groups: neutral (-10˚ to 10˚) and awkward (>-10˚ or > 10˚). WSR: playing with the ergonomic chinrest without a shoulder rest. SR: playing with the ergonomic chinrest with a shoulder rest. UC: playing with their usual chinrest and shoulder rest. IQR: interquartile ran

13.3 Implications for Study III

After conducting Study II, some changes were made before the next Study III. The implications for Study II are listed below.

13.3.1 Motivation question and recruitment materials

The motivation question was slightly modified to include the word "motivation". Additionally, an extra question was added to gather more information about the population and their interest in ergonomic equipment. The participants' motivation proved valuable for recruiting and retaining participants in the larger Study III [147].

During Study II, insights were gained indicating that the recruitment process would likely be straightforward for Study III, as evidenced by the successful recruitment within a few days. The information obtained about participants' motivation in Study II was incorporated into the recruitment process for Study III. This led to creating of a recruitment video [148] and a recruitment letter for Study III (refer to Appendix D: Recruitment Letter).

13.3.2 Self-developed questions

To ensure face validity, all participants were asked on the test day if they understood the diary questions and questionnaires and if they believed they accurately measured the intended constructs by going through each question. Based on the answers few changes were made, which can be seen here:
The efficiency question (adjustment of EC) allowed participants to answer “not yet,” which we found was a bit redundant because it would also mean no. Therefore, the diary question in study III changed to be dichotomous with the reply “yes” or “no”.

The sound was evaluated without the participants being blinded, so for Study III, we ensured that the participants were blinded before evaluating their sound recording. We also included the many factors (string crossing, technique etc.) that can influence the performance quality of violinists, which have been studied in a previous study [142].

13.3.3 Familiarisation period

If the participants got ill and were interrupted for five days, they got extended by seven days extra, additionally to what they were missing in the beginning. This was evaluated, and the participants that got extended expressed that the extension was too long, and they quickly found back to where they left off (playing setup) before their illness. Therefore, based on this, we reduced it to two days extension.

13.3.4 Objective measures

When using the ViMove system, we discovered some accuracy problems. Especially the accuracy of measuring the rotation of the head was a problem because of magnetic drift up to 30-40 degrees in either one or the other direction, but this was not consistent. Therefore, we planned not to use ViMove in Study III even though it is time effective and easy to use but with measurement errors that would be critical to interpret. This issue was only superficial mention in the validity study of ViMove [143].

To summarise the implications for Study III, we revised the motivation question and added an additional question. We changed the efficiency question to be dichotomous and included blinding of the participants when evaluating their sound. Furthermore, the ViMove system was excluded due to accuracy issues.

14 Study III

This study aimed to investigate and compare upper body kinematics and muscle activation patterns during violin playing between a usual chin and shoulder rest and an ergonomic adjustable chinrest and low shoulder rest. Secondly, to explore the user experience of violinists using the ergonomic chinrest, including motivation, usage behaviour, usability, and acceptability.

14.1 Methods

The design of this study was a crossover, block-randomised and within-subjects experimental design following the CONSORT 2010 extension to randomised crossover trials [149]. Furthermore, it included an exploration of the user experience of EC during the familiarisation period. The study started in June 2021 and ended in February 2022.

14.1.1 Study sample

The same inclusion and exclusion criteria from Study II were applied to Study III. However, in this study, the recruited participants should be professional violinists and were mainly recruited from professional symphony orchestras in Denmark and a Danish Conservatory. All participants should have graduated from a music conservatory with violin as their main instrument or attended a conservatory and enrolled on the master or soloist class. Further recruitment was also made through social media and word of mouth. A recruitment video [148] and a letter (appendix D: recruitment letter) were used for recruiting participants.

14.1.2 Intervention

The familiarisation period was the same as in Study II, but the introduction videos were reduced from three to two due to changes in the protocol [139,140]. Furthermore, only two days' extensions were given after a consecutive interruption of five days due to, e.g., illness. On the test day, EC and UC were tested during a 3-hour session and evaluated randomly, with a five-minute wash-out period incorporated to avoid any possible carryover effects between each condition [150]. The duration of the wash-out period was based on a previous study which demonstrated that professional violinists could adjust to various shoulder rests promptly, without any impact on sound quality [113]. The playing sequence (UC-EC or EC-UC) was first revealed to the participant on the test day.

The playing protocol was slightly changed from Study II by adding repetitions of the music piece for longer playing time (playing a loop of four without breaks in between) for both testing conditions.

14.1.3 Data collection

Study III expands on the measurements and findings of Study II. Any changes or additional outcome measures are described in detail below. In contrast, outcome measures from Study II that are still relevant but unchanged are briefly mentioned in the next section. The overview of the data collection can be seen in Figure 12. The green-coloured text indicates changes or additional measurements in Study III.
The test day was conducted in the attic of Bispebjerg Hospital, where we set up a laboratory. This place was chosen because it would be easy to assess from their rehearsals in their respective orchestras.

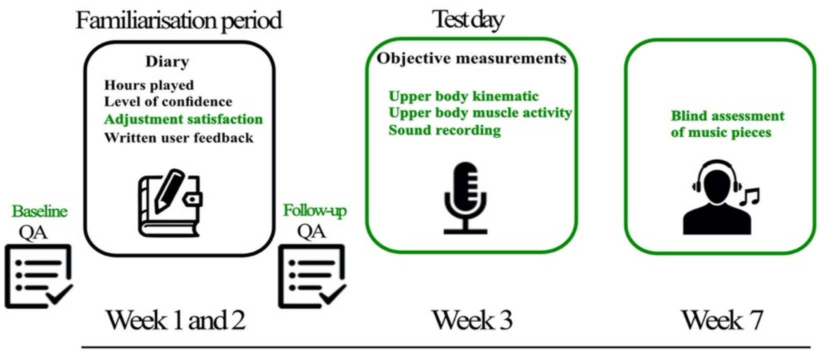


Figure 12 Overview of data collection Study III. The green text highlights the modifications or additional measurements conducted in Study III compared to Study II.

Subjective outcomes

Motivation

Two open-ended questions were asked of the participants in the baseline questionnaire. The first question was, *"Why are you motivated to participate in this* project?" and the second was, *"What is the most important aspect for you when testing a new chinrest?"*.

Usage behaviour

To evaluate the level of adherence, the number of days and total duration of playing time (hours, minutes) in which the EC was used were calculated.
In Study III, we extended the usability term and included the overall user experience, including data collection on design, acceptability, and subjectively judged workload demands [122].

Usability

From Study II, the outcomes of the effectiveness (confidence level and performance) and satisfaction (comfort and emotions) were unchanged and remained the same in Study III. The efficiency (adjustment) outcome with the question: *"Have you found an adjustment of Kréddle that is working for you?"* could now only be answered by *"yes"* or *"no"*.

Design and Acceptance

We developed one open-ended question about the design of Kréddle compared to their usual chinrest and the second question about their future use of Kréddle where they could answer "*yes*", "*no*", or "*I will consider changing at some point*". The questions were: *"What do you think of the appearance/design of the Kréddle chinrest compared with your usual chinrest?"* and *"Are you considering using the Kréddle from now on?"*

Objective outcomes

Measurements of chinrest height and neck length

We measured the height adjustment made with EC and UC from the top of the table to the highest point on the chinrest (I). The distance from the top of the table to the bottom of the violin would be the measurement of the shoulder rest height (II). This measurement was done in the middle (the bottom), and all measurements were taken with a digital caliper ruler (Figure 13).

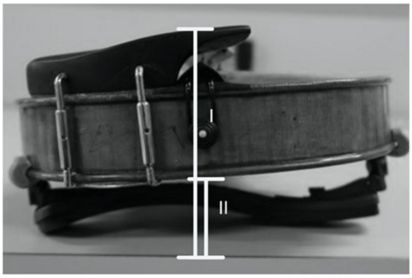


Figure 13 Measurements for Height Adjustments. The different measurements were taken to evaluate the height adjustments when using EC and UC.

The lateral neck length on the left (LNL) is not reported in any of the papers (I-IV) and is additional information in this dissertation. LNL was measured twice down to 0.1 cm, and the participant was placed in a seated position in a chair, ensuring that their back was firmly supported by the chair's backrest. The measurement was taken with a measuring tape between the mandibular angle and down to the mid-portion of the ipsilateral clavicle (Figure 14). A standard derived from a previous study [151].

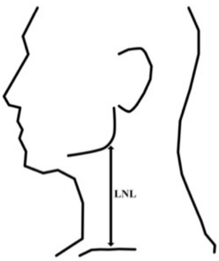


Figure 14 The measurement of the lateral neck length (LNL)

Electromyography (EMG)

The violinists were equipped with wireless surface EMG (Myon 320, AG, Switzerland) before playing under two conditions (UC and EC). Bipolar electrodes (Ambu Blue, Sensor) were placed with an interelectrode distance of 2 cm parallel to the muscle fibers. Muscle activity was measured from eight different muscles: the upper trapezius (bilaterally UT), upper neck extensor (bilaterally NE), sternocleidomastoid (bilaterally SCM), left anterior deltoid, and right medial deltoid (DT). The placement was done on cleaned skin according to standard recommendations [152], and the placement of the electrodes followed the literature [153].

See pictures of placement in Figure 15.

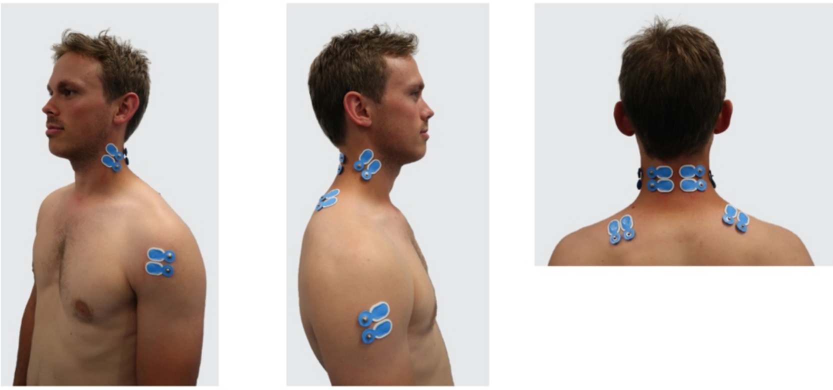


Figure 15 Showing the electrode placement on the upper body.

The highest EMG value detected for UT, NE, SCM, and DT during six maximal voluntary isometric electrical contractions (MVIC) was used for normalisation. The MVICs were slightly modified for this study but have previously been validated [154–156]. A standardised warm-up (10 shoulder elevations, arm swings, neck flexion and extension) was done before the MVICs that were done in a randomised order, including a one-minute break between each MVIC to eliminate the risk of fatigue. Each MVIC was done three times. Because we did not measure the force, we had the participants to self-evaluate their effort by making them rate the MVIC on a scale from 0 (no effort) to 10 (maximal effort) right after they did it. A score below eight released a retrial to ensure maximal performance.

Motion capture system: Vicon

Vicon motion capture system is a widely used three-dimensional (3D) lab-based system that is considered the gold standard in human movement analysis with high validity for neck and head motions [157,158] and a low mean error of 0.9 mm [159]. The Vicon Motion Systems (Ltd., Oxford, UK) consisted in this study of eight infrared cameras, one high-speed digital camera and 18 reflective surface markers that were used to measure upper-body kinematics. We placed all the cameras 1-2 meters away from the participant sitting in a 36m2 heated room (Figure 16).

We followed the recommended guidelines for marker placement [160] and used a neck model built on reasonable assumptions about joint motions [143,161,162]. The Nexus software (version 2.12) from Vicon controlled the cameras at a sampling frequency of 200 Hz.

Figure 16 The Vicon motion capture system used in the attic at Bispebjerg Hospital.

We used ProCalc from Vicon (version 1.5.0) to calculate the joint angles. See more specific details in paper III.

Self-reported muscle activity and head alignment

In the follow-up questionnaire, participants were asked to subjectively evaluate their muscle activity and head alignment while playing with EC during the familiarisation period. These questions were inspired by a previous study where participants self-evaluated the effects of

specific training to reduce muscle activity and improve posture (i.e., Alexander technique) [163]. Although not reported in any of the papers (I-IV), these three questions are provided as additional information in this dissertation:
Do your shoulder muscles become tighter than usual when you play using Kréddle?
Do your neck/throat muscles become tighter than usual when you play using Kréddle?
Do you keep your head and neck straighter/more vertical than usual when using Kréddle?
The questions are answered on a 5-point Likert scale from “not at all” to “extremely”.

Sound

The sound was recorded using an Olympus LS-10 stereo digital recorder and two miniature microphones attached to the music stand. Each participant received their recording via email one month after the test day. The recording included six files (three with EC and three with UC): four warm-up scales (two in A major and two in E major) and two with the music piece. This dissertation focuses on the music piece, not the scales, which were included to make the guessing more challenging.
The recordings were marked A-F and randomised. Firstly, participants were asked to guess for each file if the recording had been played with EC by answering “*yes*”, “*no*”, or “*don’t know*”. Secondly, they responded to questions inspired by previous work investigating factors influencing overall performance quality [142]. The questions, which could be answered on a 5-point Likert scale from *"very good"* to *"very poor",* were:

1) How does your technique sound overall?
2) How is the tone of your violin playing in relation to fulness and power?
3) How does your string crossing sound? (in relation to controlled and smooth)?
4) How is your overall perception of the quality of your performance?
5) How is your musical expression and interpretation?

14.1.4 Data analysis

Quantitative data

The following section will describe specific statistics used in Study III that differ from Study II.

EMG and Vicon data

After checking for normality, we used a linear mixed-effects model for the EMG and Vicon data. Fixed variables were the treatment (either UC or EC) and period effect (the order of UC or EC as the period 1 and period 2 with the order EC or UC) and the subjects as the random component [150]. We assumed the absence of a carry-over effect using a five-minute wash-out period, which is the recommendation from the latest CONSORT statement for randomised crossover trials [149].

We used an Amplitude Probability Density Function (APDF) to identify the head kinematic and muscle activity levels: P0.1, P0.5 and P0.9. The APDF can determine the levels of head motion or muscle activity that occur most frequently and the likelihood of their occurrence. Furthermore, we used an exposure variation analysis (EVA) on one specific muscle that have shown the largest muscle activity change. Using this analysis, we could identify patterns and variations in muscle activity levels over time and gain information on whether EC or UC affected muscle activity during an activity or was quite the same over the whole period. The EVA comprises a matrix with the percentage of cumulative time (%), amplitude level (>0-1, >1-3, >3-5, >5-10, >10-20, >20-30 and >30% EMGmax) and length of time at each amplitude level (>0-1, >1-3, >3-7, >7-15, >15-31, >31-63, >63-127 and >127 seconds).

As in Study II, we calculated the time spent in awkward playing posture above 10 degrees and used a Wilcoxon signed rank test due to the distribution.

Neck length

A Pearson correlation between the self-adjusted height (cm) for UC and EC and neck length (cm) was conducted after checking for the normality of the data.

Sound

We conducted a binomial probability test using a sample size of 6 audio files and a probability of success (distinguishing between two conditions) of 0.05. This would give a probability of 0.03 distinguishing between UC and EC, and we would expect 1.1 violinists to guess correctly or incorrectly on all six audio files.

A Wilxocon sign rank test was used to test the differences between the questions about tone, string crossing etc.

Self-reported and objective outcomes on muscle activity

The workload measured from Vicon and EMG was used to compare the qualitative data on their self-evaluated head alignment and muscle tension. This was done descriptively.

Sample size

Based on the data provided from Study II, the sample size had to be 34 violinists in Study III. This was based on the head position being either neutral or awkward, with a power of 80% and a statistical significance of 5%, detecting a difference of 0.25 between the marginal proportions.

Qualitative data

The data were analysed as described in Study II.

14.2 Results

14.2.1 Recruitment, participants and motivation

In total, 62 participants agreed to participate; however, due to covid-19, described in section 10.2. Twelve participants withdrew due to sick leave, lack of time, or suddenly unreachable. Only three participants were excluded due to our exclusion criteria.

Forty-seven participants were included with a permanent contract with a symphony orchestra.

Only violinists in five of the seven orchestras got invited (n=138), which means we recruited 34.1% of this population. The reason for not inviting the other two orchestras was due to the time and the cost of moving the Vicon equipment, which was time-consuming and needed a specialist every time to set it up for one whole working day.

In total, 38 participants were included and analysed, with nine dropping out due to health issues, family reasons, and job situations. See more details in paper III.

The professional violinists were 28 participants with a permanent contract in one of the five Danish symphony orchestras, three conservatory students and seven professional violinists (defined as freelance violinists or teachers).

We recruited 26 females and 12 men with a mean age of 42.6 years old (SD 12). Five different themes emerged from their answers about their motivation, including two additional themes when asking about important aspects when trying a new chinrest. See the themes in Table 5.

Table 5 Themes on Motivation and Chinrest Importance. The different themes emerged from questions about motivation and important aspects of playing with a new chinrest.

Question	Themes
Motivation	Ergonomics: working posture Sound Health: less muscle tension Performance Find a new product
Important aspects when trying a new chinrest	Comfort Product material and appearance

14.2.2 Objective outcome

Head kinematic

No difference was found in time spent in the awkward head position between UC (median 10, IQR 27.3) and EC (median 11.0, IQR 26.1). Additionally, we observed that half of the participants (19 out of 38) experienced a decrease in their time spent in the awkward head position, while the other half experienced an increase.

In Figure 17, the APDF analysis revealed no difference between the playing conditions with a P0.1 level around 6° to the left and 6° and more to the right at the P0.9 level. The additional angles measured in Study III for head extension/flexion and rotation showed significant but minor differences at P0.1 with 1.4° less head extension and 2.5° less left head rotation using EC compared to UC. Overall, during 90% of the playing time, the violinists positioned their heads tilted 6° to the left, with a head extension of approximately 1°, and rotated to the left at an angle of approximately 15°, regardless of whether they were using UC or EC.

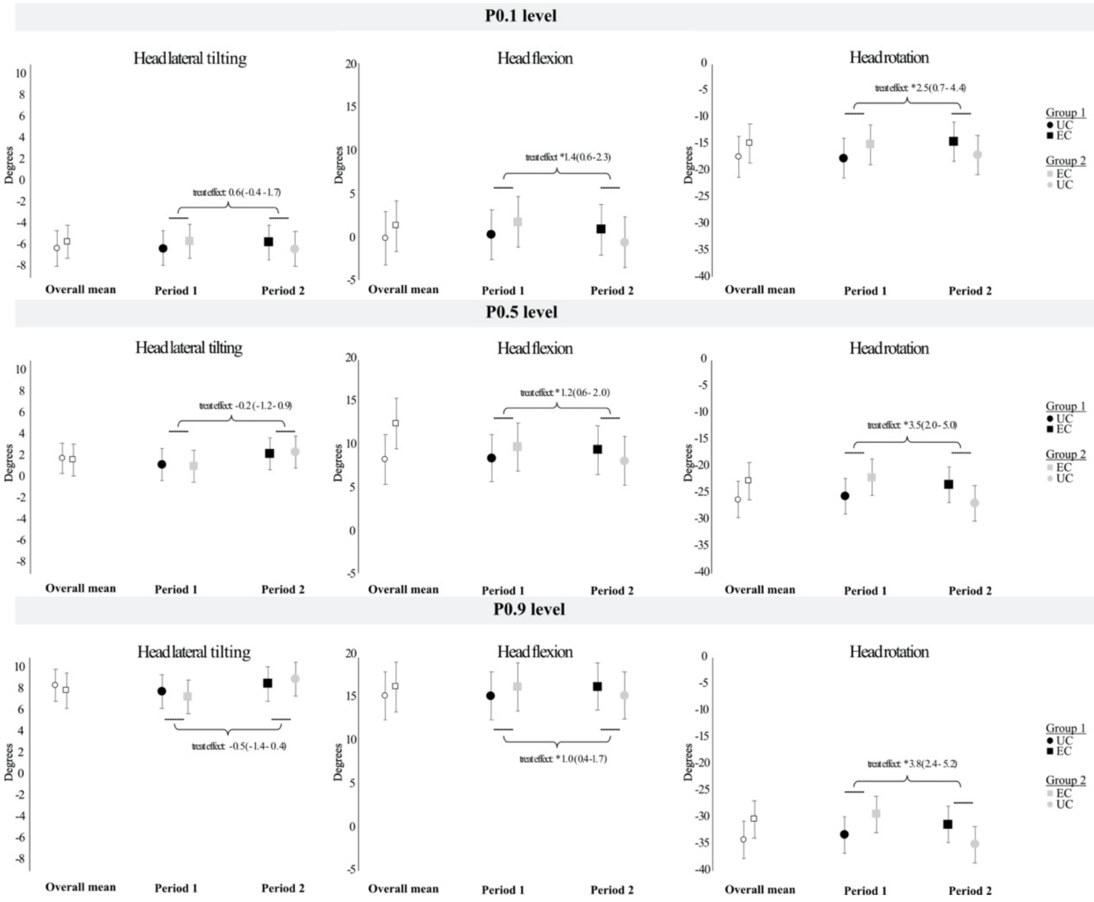


Figure 17 The Amplitude Probability Distribution Function illustrated the head posture. Kinematic angles (◦) with 95% confidence intervals (CI) were used to assess the overall mean and static, median, and peak levels of head posture. The comparison of test periods 1 and 2, conducted in randomised playing orders UC-EC and EC-UC respectively, enabled the determination of the treatment effect, representing the difference between UC and EC. A significant distinction between UC and EC, denoted by an asterisk (*), was observed for p-values ≤ 0.05. EC referred to the ergonomic chinrest used with a shoulder rest, while UC represented the usual chinrest and shoulder rest.

EMG

In Figure 18, the EMG data revealed muscle activity levels for the static, median and peak levels that were almost the same, with only a few percentage changes for all muscles. The static levels for all muscles were below 10 %MVE and below 15 %MVE for the peak level. Minimal differences (below 1 %MVE) were found for UT, NE and right SCM using EC. The most significant muscle activity change was found in the right SCM (1 %MVE). Still, the EVA analysis did not reveal any clear difference in short or extended durations of muscle activity patterns using either UC or EC, as seen in Figure 18.

Chinrest height

The results demonstrate a statistically significant increase in total height when using EC (median 12.6 cm) compared to UC (median 11.3 cm). No significant difference was observed in shoulder rest height between the two conditions.

There was a moderate positive correlation between the neck length and adjusted height of EC, $r(36)= .51$, $p<.001$ and a strong positive correlation between adjusting the height of UC to the neck length, $r(36)= .68$, $p<0.0001$.

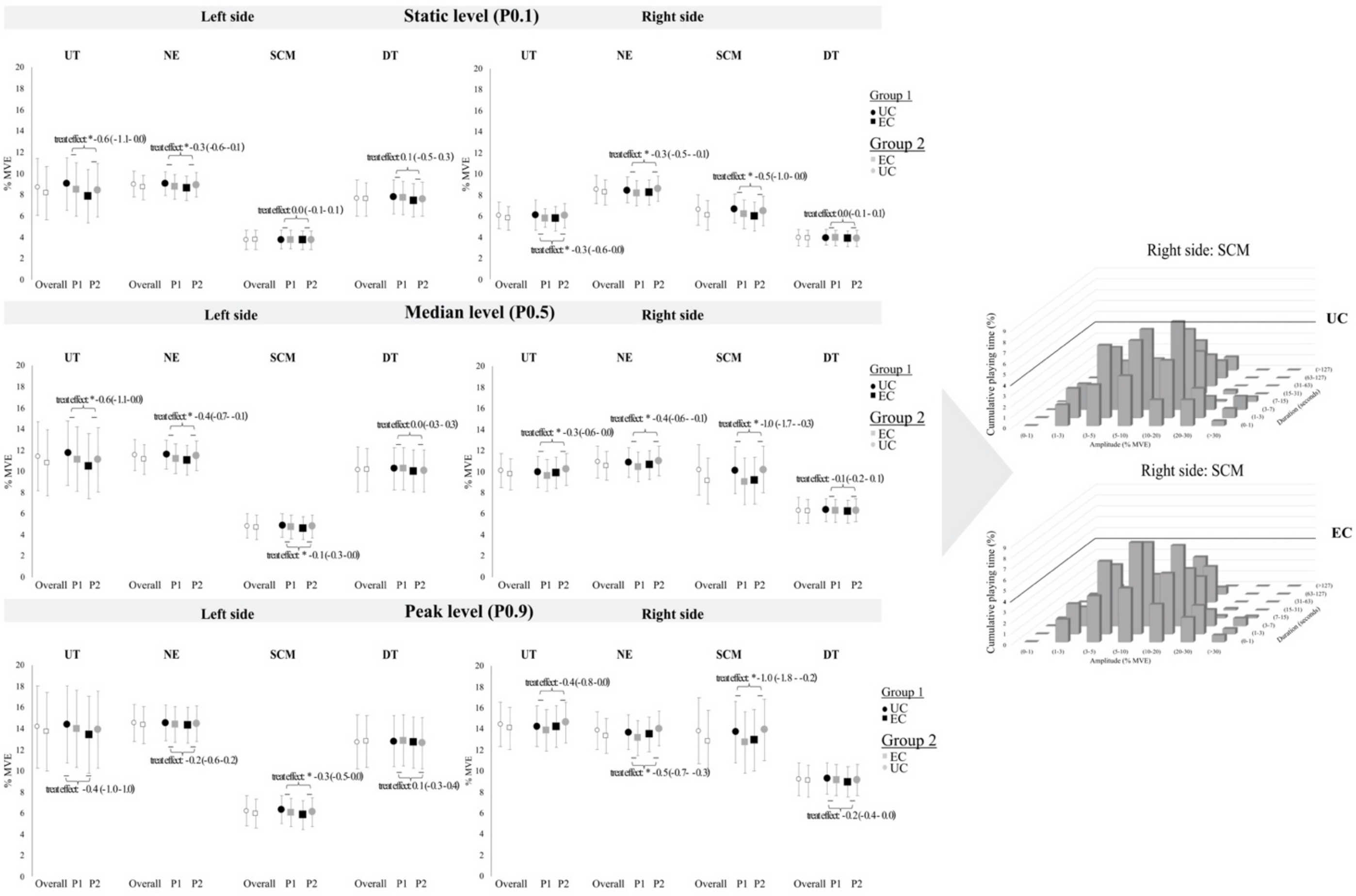

Static level (P0.1)
Left side
Right side
UT
NE
SCM
DT
% MVE
Overall P1 P2
Group 1
UC
EC
Group 2
EC
UC
treat effect: * -0.6(-1.1- 0.0)
treat effect: * -0.3(-0.6- -0.1)
treat effect: 0.0(-0.1- 0.1)
treat effect: 0.1(-0.5- 0.3)
treat effect: * -0.3(-0.6- 0.0)
treat effect: * -0.3(-0.5- -0.1)
treat effect: * -0.5(-1.0- 0.0)
treat effect: 0.0(-0.1- 0.1)
Median level (P0.5)
treat effect: * -0.6(-1.1-0.0)
treat effect: * -0.4(-0.7- -0.1)
treat effect: * -0.1(-0.3-0.0)
treat effect: 0.0(-0.3- 0.3)
treat effect: * -0.3(-0.6- 0.0)
treat effect: * -0.4(-0.6- -0.1)
treat effect: * -1.0 (-1.7- -0.3)
treat effect: -0.1(-0.2- 0.1)
Peak level (P0.9)
treat effect: -0.4 (-1.0-1.0)
treat effect: -0.2(-0.6-0.2)
treat effect: * -0.3(-0.5-0.0)
treat effect: 0.1(-0.3-0.4)
treat effect: -0.4(-0.8-0.0)
treat effect: * -0.5(-0.7- -0.3)
treat effect: * -1.0 (-1.8 - -0.2)
treat effect: -0.2(-0.4- 0.0)
Right side: SCM
UC
EC
Cumulative playing time (%)
Amplitude (% MVE)
Duration (seconds)

Figure 18 The muscle activity (%MVE) in the upper body. Measurements made for Upper Trapezius (UT), Upper Neck Extensor (NE), Sternocleidomastoideus (SCM), Left Anterior Deltoideus (DT), and Right Medial Deltoideus. The data is presented with 95% confidence intervals (CI). The measurements include static (P0.1), median (P0.5), and peak levels (P0.9), along with the overall mean and data from periods 1 and 2. The treatment effect (treat) represents the difference in %MVE between UC (usual chinrest and shoulder rest) and EC (ergonomic chinrest with shoulder rest). An asterisk (*) indicates statistical significance ($p \leq 0.05$) between UC and EC, with periods 1 and 2 considered as fixed variables. The muscle activity in the right sternocleidomastoid (SCM) was analysed using Exposure Variation Analysis during the UC and EC conditions. The matrix illustrates the correlation between cumulative playing time (%), muscle activity amplitude (%MVE), and the duration spent at each amplitude level (in seconds).

Subjective Outcomes

After playing with EC for two weeks, the participants mainly had negative comments about the design (25 out of 38), and the performance was significantly affected compared to UC (p=0.03). Moreover, we found that the participants could distinguish between the sound (p=0.001) (although not guessing which sound belonged to which conditions). However, the sound recording regarding the performance quality was scored worse for EC than UC (p=0.02). The comfort score was not affected, and it only took a median of 2 days to adjust and be confident using EC (Table 6).

Overall, we observed more negative comments (n=213) than positive comments (n=163). These comments led to the identification of three themes: adjustment and body posture (first theme), pain experienced (second theme), and, in some cases, an impact on sound quality (third theme). In the second week, we observed a decrease in negative feedback, while positive feedback continued to revolve around the same themes. Participants reported becoming accustomed to the product and noted improvements in terms of adjustment, body posture, and pain alleviation (Figure 19). The sound was for some participants not affected, and they found it better sometimes with EC. In total, 37% want to continue to play with EC after the end of the project. More details about the findings can be read in paper IV.

Table 6 Usability Outcomes for Study III.

Questions	UC (mean, 95% CI)	EC (mean, 95% CI)
Comfort level	31.2 (25.4-36.9)	37.0 (31.3-42.6)
Performance level*	14.9 (8.3-21.5)	30.5 (22.7-38.3)
Sound : Tone, string crossing, technique, musical expression and interpretation, quality of performance*	no difference *difference (p=0.02)	
Audio guessing	12 able to distinguish and guess either correct or wrong*	

	8 out of 12 could not guess that the audio recording was EC.

UC: usual chinrest and shoulder rest. EC: Ergonomic chinrest played with shoulder rest. An asterisk (*) indicates statistical significance ($p \leq 0.05$) between UC and EC.

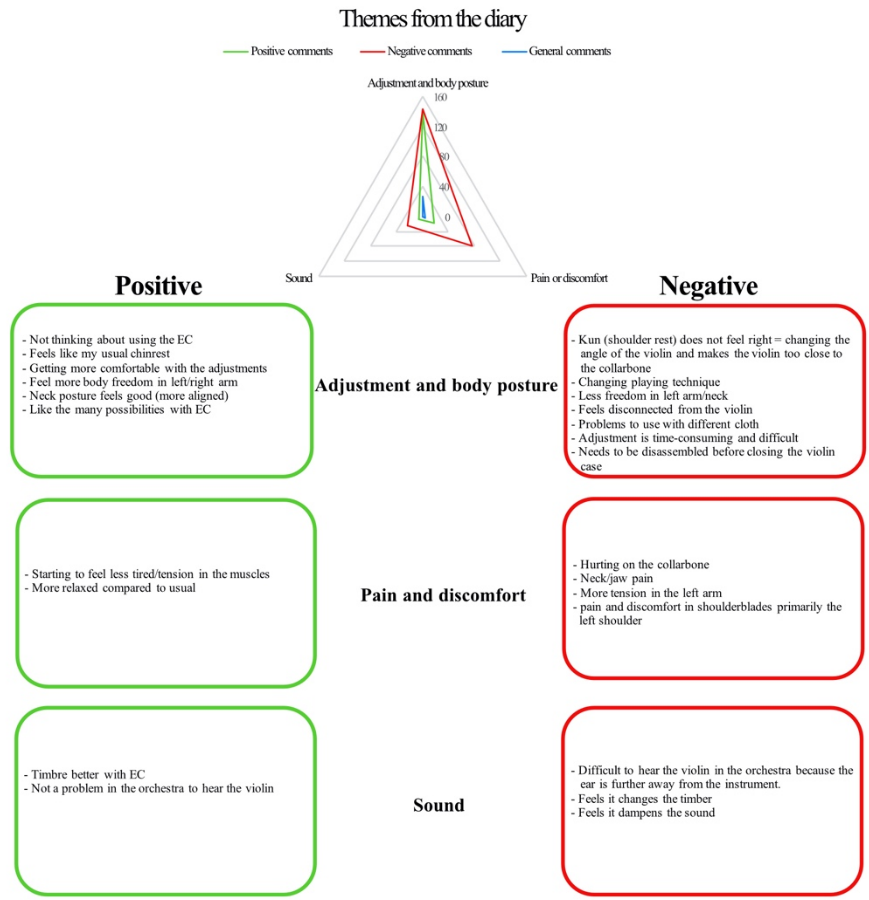


Figure 19 Overview of the themes that were found in the diary (positive and negative comments). EC: Ergonomic chinrest with shoulder rest.

Objective and subjective outcomes of muscle activity and head alignment

In Study III, we obtained subjective and objective outcomes regarding muscle activity and head alignment. Although these data have not been included in Papers III or IV, they are presented in this dissertation. The objective measurements indicated minimal changes (less than 1%MVE) in muscle activity for UT and NE/SCM, and the amount of time spent in awkward positions was only 1.2% higher for UC than for EC. Generally, no substantial differences between playing with UC or EC regarding kinematics or muscle activity were observed.

The subjective outcomes showed that 81.1% and 82.3% of participants reported feeling "*not at all*" or "*a little bit*" of change when playing with EC for the UT and NE/SCM muscles, respectively. The subjective outcome of feeling no change or a little bit was correlated with objective outcomes below 2.5 %MVE. However, one participant did not feel any difference for UT, despite objective measurements indicating above 3%MVE muscle change (i.e., less muscle activity using EC). Despite this, the objective measures supported one participant's most self-reported muscle changes. We also found that extreme feelings of change (n=6) were not correlated with significant muscle activity changes (Figure 20).

Regarding head alignment, 44.7% of participants reported feeling more aligned with EC, although this was not supported by objective measurements of time spent in an awkward position. Only four participants were somewhat correlated with less time spent in awkward positions with EC (16-25%) and subjectively stating "*quite a bit*" or "*extreme*" changes. Figure 20 provides an overview of the subjective and objective measurements.

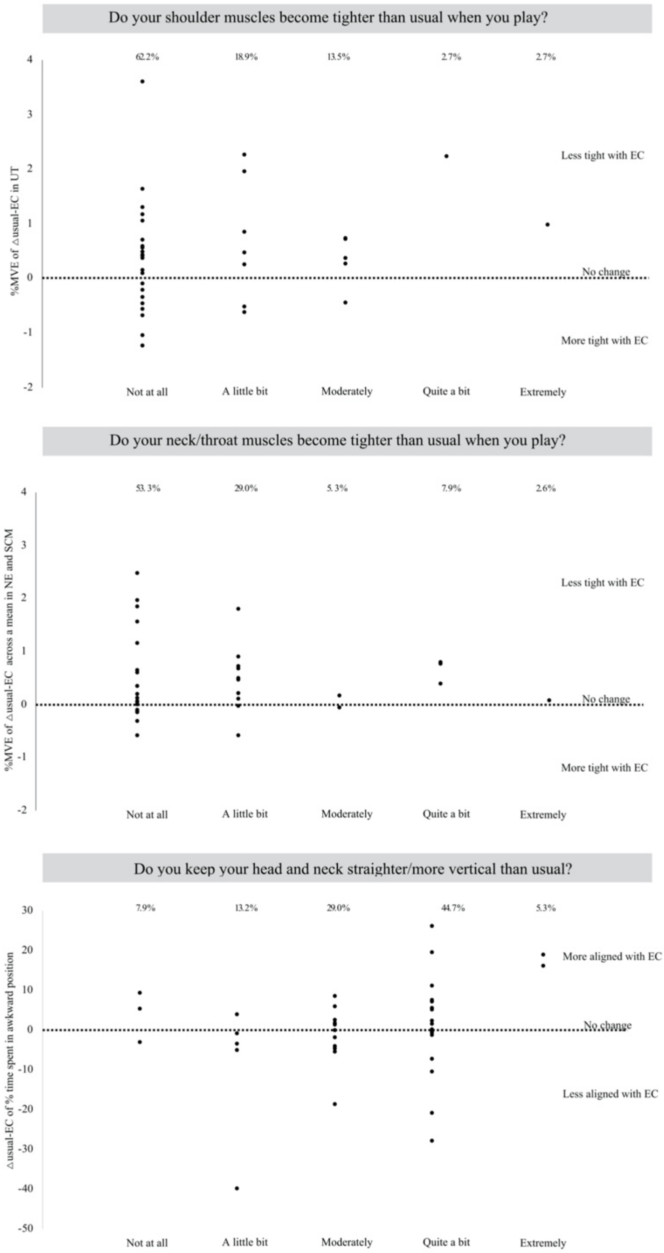


Figure 20 Overview of the subjective and objective measurements of muscle tension and neck alignment. The objective findings of changes have been calculated between UC (usual chinrest and shoulder rest) and EC (ergonomic chinrest with shoulder rest).

15 Summarise of methods across Studies I-III

The following two sections, *summaries of methods and results*, provide a concise overview of the content presented in this dissertation. More detailed information and explanations of outcomes/results can be found in the respective studies and papers.

An overview of the methods used from Study I-III is presented in a table format (Table 7) and a graphical version (Figure 21), with yellow representing changes or additional outcomes applied in Study II and III.

Table 7 Overview of methods used across all Studies (I-II

Subjective method	**Study I**	**Study II**	**Study III**
Demographics	x	x	x
Acceptability	x		x
Motivation		x	x
Instruction comprehensiveness	x	x	
Comfort	x	x	x
Performance	x	x	x
Adjustment		x	x
Confidence		x	x
Emotions		x	x
Sound		x	x
Design			x
Workload			x
Objective method			
RULA	x		
ViMove		x	
Vicon			x
EMG			x
Sound			x

RULA: Rapid Upper Limb assessment, ViMove and Vicon: body motion capture systems, EMG: Electromyography

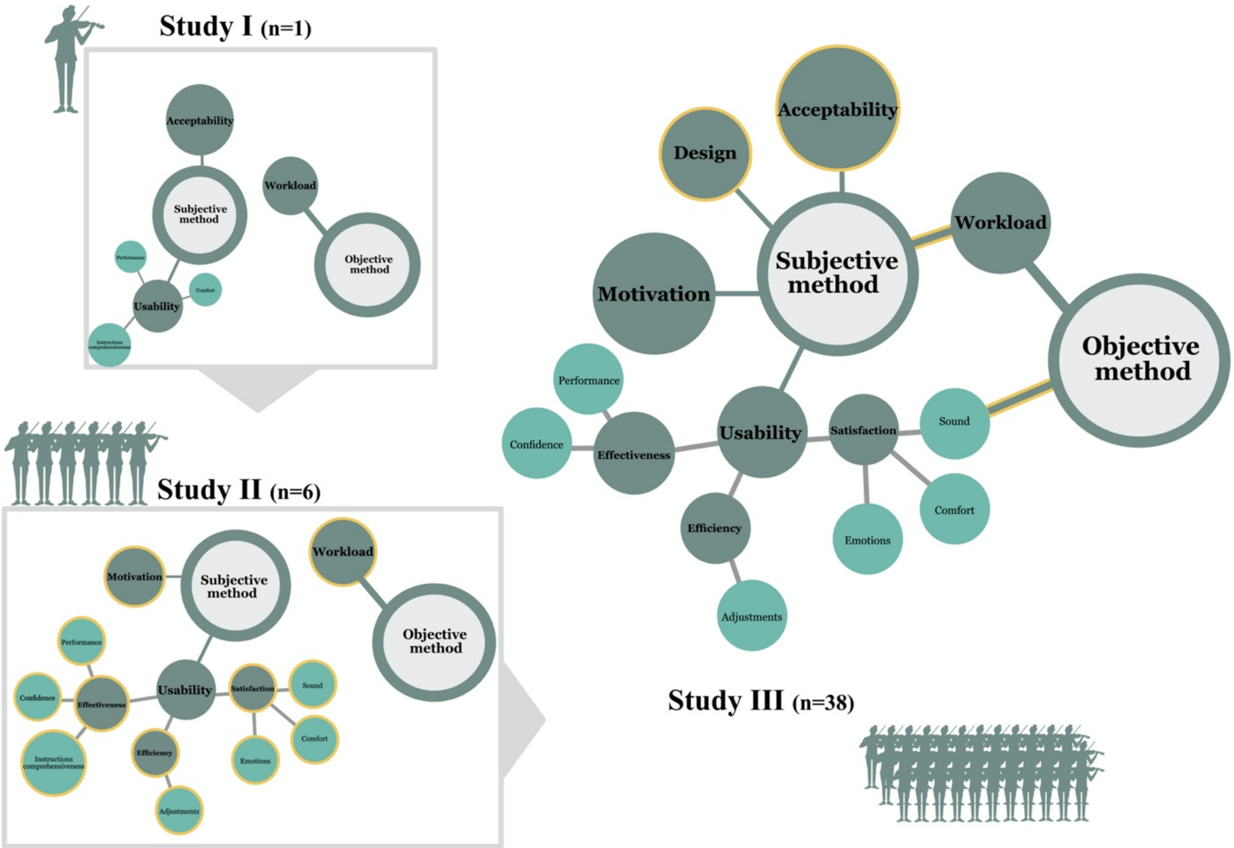


Figure 21
Overview of the different methods used across all Studies I-III. Yellow represents the changes or additional measures.

16 Summarise of results across Studies I-III

In this section, the overall findings of Studies I-III are summarised. The first Table 8 displays the different studies' recruitment processes and demographic characteristics. Tables 9 and 10 display the objective and subjective outcomes, followed by the last Figure 22, highlighting the overall implication changes and results across Study I, II and III.

IQR= Interquartile range. *Indicate that this number represents the age at which the case started playing viola and violin, respectively.

Table 8 Flowchart and baseline characteristics across Studies I-III.

	Study I	Study II	Study III
	Recruited: n= 1 Eligible: n=1 Drop-out: n=0	Recruited: n= 6 Eligible: n=6 Drop-out: n=0	Recruited: n= 62 Eligible: n=47 Drop-out: n= 9
	Total analysed (n=1)	Total analysed (n=6)	Total analysed (n=38)
Baseline characteristics			
Male/Female	0/1	3/3	12/26
Age, mean (SD)	32	35 (9)	42.6 (12)
Daily practice the last 12 month (hours), median (IQR)	6	3.2 (1)	4.5 (1.5)
Age starting with main instrument (years), median (IQR)	17/7*	7.5 (2)	7 (3)

Table 9 Objective outcomes of head position across Studies I-III. An awkward position is defined as >10° to either the left or right side. Different objective measurement methods are used in the different studies.

Study I	**UC**	**SR**	
RULA score in points Overall score: Neck score:	 5-6 3	 5-6 2	
Study II	**UC**	**SR**	**WSR**
Time spent in awkward position (%), median (IQR)	15 (26)	8.5 (4)	8.5 (13)
Study III	**UC**	**SR**	
Time spent in awkward position (%), median (IQR)	10 (27.3)	11 (26.1)	

RULA: rapid upper limb assessment. IQR: interquartile range. UC: usual chinrest and shoulder rest. SR: ergonomic chinrest played with shoulder rest. WSR: ergonomic chinrest played without shoulder rest.

In studies I-III, no significant difference was found between UC and SR or WSR in terms of overall RULA score (Study I) or the duration of awkward head position (Study II and III) (Table 9).

In both Study II and III, the performance score was significantly affected among the usability outcomes when using the ergonomic chinrest. Additionally, in Study III, only the sound was found to be affected. Moreover, during the two-week period in both Study II and III, more negative comments were given than positive ones (Table 10).

Table 10 Subjective outcomes: usability across Study I-III.

Questions	**Study I** (n=1)	**Study II** (n=6)	**Study III** (n=38)
Effectiveness			
Instructions comprehensiveness (yes/no) (n)	Not working	6/0	*x*
	SR follow-up	*WSR/SR median*	*UC/SR mean*
Performance questions	3	58.3 /45.8* (p=0.03)	14.9/30.5* (p=0.03)
		WSR/SR median	*SR median*

Confidence (days)	x	6/5* (p=0.03)	2
Efficiency			
Adjustment (days)	x	6/1.5	2
Satisfaction			
	SR follow-up	*WSR/SR* median	*UC/SR* mean
Comfort questions	2	40/30	31.2/37.0
		WSR/SR	*UC/SR*
Sound questions 1. Overall sound 2. Tone 3. String crossing 4. Technique, 5. Musical expression interpretation 6. Quality of performance*	1. x 2. x 3. x 4. x 5. x 6. x	1. no difference 2. no difference 3. x 4. x 5. x 6. x	1. x 2. no difference 3. no difference 4. no difference 5. no difference 6. Difference (p=0.02)
Audio guessing	x	x	Of the 38 participants, 12 distinguished*, but only 4 correctly guessed SR.
		WSR/SR	*SR*
Emotions			
Total comments		33/15	420
Negative comments (n)		26/3	213
Positive comments (n)		7/12	163

WSR: Playing the ergonomic chinrest without shoulder rest. SR: playing the ergonomic chinrest with shoulder rest. UC: Playing with usual chinrest and shoulder rest. An asterisk (*) indicates statistical significance ($p \leq 0.05$) between either WSR and SR or between UC and SR.

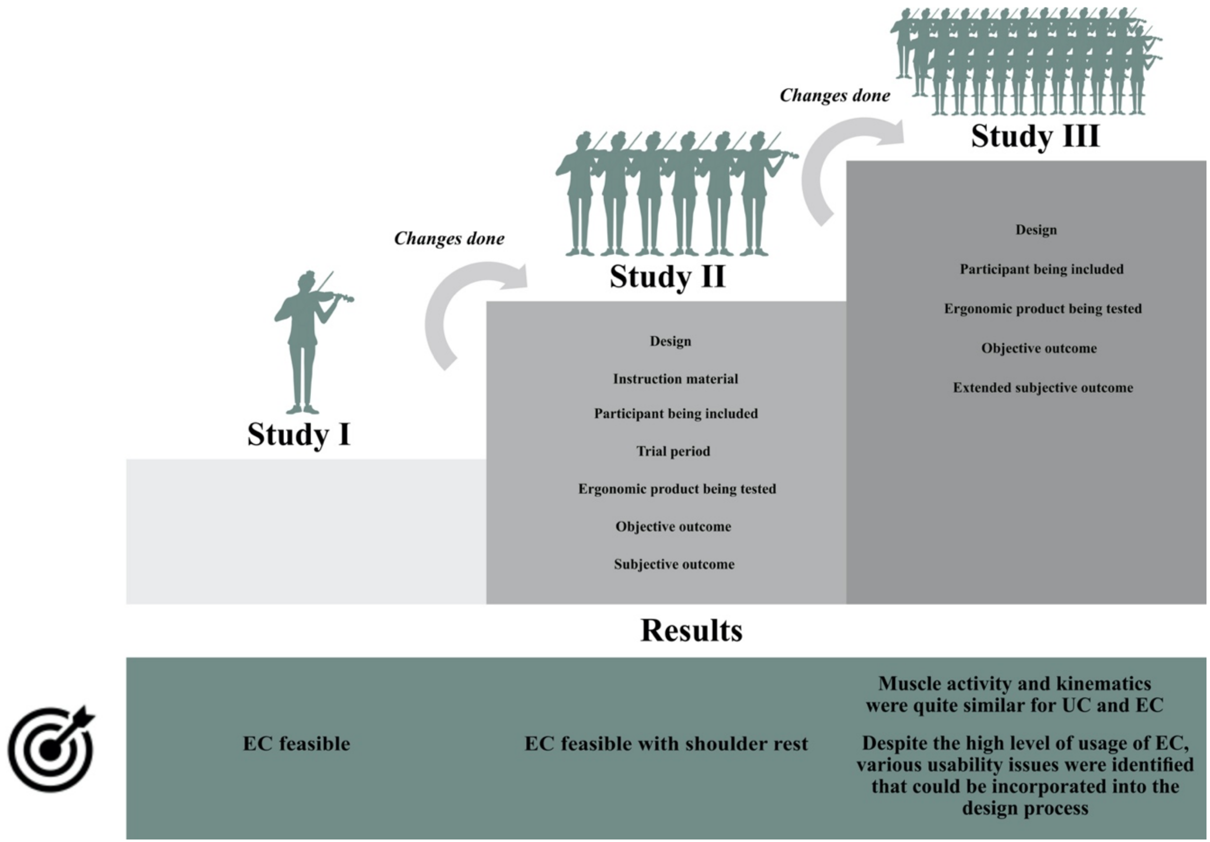


Figure 22 Overall results and changes across Studies I-III. EC: Ergonomic chinrest. UC: Usual chinrest and shoulder rest.

17 Discussion

This dissertation investigated the feasibility and user experience of using a novel EC and compared its biomechanical working conditions with those of professional violinists' usual supportive ergonomic equipment. The investigation of the selected EC was divided into two stages, with Study I and II assessing the feasibility of EC. The results of these studies led to the final investigation of Study III, which investigated the effect and user experience of EC.

17.1 Sequential Study Designs: Assessing Feasibility, Effectiveness, and User Experience

This PhD thesis encompasses three distinct study designs (Study I, II, and III) that can be aligned with the evidence hierarchy [164] for evaluating this specific EC. Each study contributes unique knowledge by assessing the ergonomic product from different perspectives. Given the scarcity of ergonomic studies conducted among violinists [103], conducting a case study as an initial step allows for an in-depth exploration and understanding of the EC's use in a real-world context. The case study provided valuable insights into a user's experience, perspective, and challenges when using the product. These findings helped identify potential implications (section 12.03) before further investigation (Study II), enhancing external validity.

Study II, a feasibility study conducted before a larger scale study (Study III), aimed to determine the achievable and worth pursuing Study III testing all the different conditions (SR, WSR and UC). It examined the potential success or failure of implementing EC on a broader scale beyond assessing its efficacy. Study II also yielded implications for Study III, including only testing SR further (section 13.03).

In Study III, a crossover design was a control condition where we tested two conditions (EC and UC) with one group of participants (n=38). Using the same individuals as their own controls allowed for a larger effective sample size and facilitated direct within-subject comparisons, minimising confounding factors and providing robust evidence of the EC's effects.

Several major implications emerged from the three studies: 1) The recruited study sample comprised individuals without pain, 2) changes in the instructions provided, 3) changes in usability outcomes and measurement methods, 4) transitioning from RULA-ViMove to Vicon for objective outcomes, and 5) testing the product (EC) with SR due to the lack of feasibility of WSR.

In Study II and III, we treated the written user feedback as qualitative data, contributing to a comprehensive understanding of the participants' experiences. Incorporating qualitative and quantitative data in all studies provided a holistic perspective on the real-world implications of the ergonomic product.

The written feedback offers the advantage of participants freely expressing their thoughts and experiences without direct influence from an interviewer or external factors. This can provide a more authentic and unbiased representation of their perspectives. Additionally, participants may feel more comfortable expressing their opinions and providing detailed feedback in a written format, leading to a richer and more comprehensive dataset. However, including follow-up qualitative interviews would have enriched the study, providing more in-depth details about participants' experiences. These interviews could have uncovered unexpected insights and valuable contextual information not fully captured through written user feedback alone. They would have complemented the initial phase of written feedback, allowing for a deeper exploration of emotions, beliefs, perceptions, and preferences, enhancing the overall understanding of participants' interactions with the ergonomic product before, during and after [101].

Conducting the studies sequentially allowed for evaluating the ergonomic product across multiple dimensions, including feasibility, user experience, and effectiveness compared to the do-as-usual (UC) approach. This sequential approach ensured the success of Study III while enhancing the credibility and applicability of the findings regarding the ergonomic product's use. Furthermore, comparing the test product (EC) with a do-as-usual condition (UC) enhances the study's internal validity by isolating the test product's specific effects and minimising potential confounding variables. To the best of our knowledge, a limited amount of research directly compares a violinist's usual setup (UC) with alternative playing conditions [103].

We found one study from the year 1997 [114] that compared a violinist's UC with another playing condition. However, in that study, the UC condition was compared to a different violin equipped with ergonomic products, introducing an additional variable (the instrument) that could impact the outcomes. The effects of the other conditions measured in that study cannot be exclusively attributed to the ergonomic product tested since the violin used becomes a confounding variable in the analysis.

Study II also had a secondary aim, which produced similar results to the crossover study (Study III). No significant differences were found in time spent in awkward head alignment among the three conditions investigated in Study III (UC, WSR, and SR) or head alignment compared to the two conditions (UC and EC) tested in Study III. This convergence of results indicates that the feasibility study successfully captured the intended effect of the ergonomic product, providing supporting evidence for the lack of a significant impact. These findings strengthen the credibility of the feasibility study (Study II) and support its methodology and sample (even with only six participants included). The consistency of findings observed across the feasibility and crossover studies enhances confidence in the research outcomes. This consistency demonstrates the reliability and replicability of the observed effects. It fosters greater trust in the derived conclusions that there is no substantial effect of using EC compared to UC (Study III). These consistent results further suggest that the findings are likely reliable and applicable in practical contexts.
The primary purpose of a feasibility study was to assess the feasibility of the product [165] and not to estimate the sample size. However, in this project, it was impossible to draw on knowledge from previous research in this area or others due to the uniqueness of the ergonomic product being tested. Additionally, there was no opportunity for comparison to products in other industries.

17.2 Posture alignment and workload levels

This dissertation refers to maintaining an erect posture with the neck held straight and aligned with the spinal column and the head balanced on top of the neck using minimal muscle effort as the "optimal" aligned posture. This approach is being investigated to determine whether a novel EC can change head alignment. In the music industry, there is a belief about being in an optimal or suboptimal posture, and there is controversy about what can lead to spinal pain. Many ergonomic products, such as the EC and shoulder rest, aim to enhance posture. However, only a few studies focusing on musicians have defined what an

“optimal” playing position covers and means, which aligns with the definition used in this dissertation [166].
One of the general physical risk factors for neck pain is recognised as repetitive, precision work in awkward/sustained postures [167]. A specific study [135] investigated violinists with neck pain (n=9) and identified significant lateral head tilt (5.84°) and left-sided head rotation (mean 10.47°), along with altered muscle activity in the upper trapezius, neck extensors, and sternocleidomastoid muscles, compared to those without pain. It is important to note that our pain-free participants displayed findings (left rotation angle around 15° and left head tilting around 6°) that showed more remarkable similarity to those observed in the mentioned study involving individuals with neck pain. However, it is important to consider that our results were compared to a study conducted with different measuring tools and calibrations, which also involved participants who were students playing a different piece of music (Kreutzer). These variations in variables may potentially explain the differences observed between our pain-free group and the smaller group without pain (n=9) that was examined in that study [135].
The ergonomic products used by violinists in this study (UC) did not result in substantial biomechanical changes when using EC (Study III). In Study II and III, we observed similar results, with half of the participants increasing their time spent in the awkward head position while the other half decreased it. Furthermore, an in-depth APDF analysis of the data showed that for 90% of their playing time, they only maintained a lateral head tilt of 6° to the left and then, 10% of the time, kept to the right at 6°. However, it is primarily the left rotation angle (around 15°) that leads to an 'awkward' head position deviating from alignment, as we observe minimal extension (1°) and left tilting angles in both conditions. In a previous study involving 12 violinists and utilising a motion capture system, researchers observed similar left rotation of the head as our findings, but with right head lateral tilting and head flexion, which contrasts with our results [168]. However, it is essential to note that the violinists in that study were standing with a note stand in front of them, and their task involved playing single notes on different strings rather than performing a complete musical piece. The nature of the procedure and the positioning can significantly influence posture [166]. This influence on posture is supported by another study that observed different movement patterns among violinists positioned to the right or left side of the note stand [108].

The EC and numerous other ergonomic products designed for violinists aim to specifically modify head posture and reduce static muscle activity in the upper body. As discussed in the introduction, previous research has indicated that poor posture and static muscle activation can contribute to pain and injury [33,169]. Despite violinists' use of certain ergonomic products [18], high pain rates continue to be observed annually. Building upon this background, our hypothesis posited that comparing violinists' selected ergonomic product (UC) and the EC would reveal improved posture and reduced muscle activity. In our project, the EC would be compared to other products available on the market (UC), with the expectation that it would be highly customised to fit the players' anthropometrics and playing styles. Additionally, our focus lies on the height of the chinrest rather than the shoulder rest. Previous suggestions have indicated that setting the shoulder rest in a low position can help reduce muscle activity and adjust the head position [111]. The focus on the chinrest diverges from the current practice of violinists, as numerous online sources and ergonomic studies primarily concentrate on shoulder rest, exploring various variations [110–113].

However, our study did not identify a difference in shoulder rest height between UC and EC. Nevertheless, we did find a significant difference in chinrest height between the two conditions, with EC being adjusted higher than UC. Additionally, we discovered that neck length and the chosen height were better correlated with the UC adjustment, suggesting that participants adjusted/chose their usual ergonomic product more effectively, possibly due to their more extended experience using and adjusting it.

The participants recruited for our study were initially pain-free and represented a significant subset of violinists who, at that particular time, did not experience pain. It is important to note that this may not necessarily reflect the typical experience of violinists, as they often report higher levels of pain compared to musicians of other instruments over the course of a year [74]. However, it is worth considering that the timing of recruitment coincided with a pandemic, which could have influenced the lower prevalence of pain due to reduced working hours. Additionally, it is possible that our selection process specifically attracted participants who were already conscious of their body posture and muscle activity, which could explain the lack of significant changes observed. It is worth mentioning that participants experiencing pain or injuries may employ different body strategies compared to pain-free violinists, as observed in a previous study [135,170].

Despite the height adjustment variation between the two conditions (EC and UC) in Study III, we observed that the right SCM doubled its muscle activity from the static to the playing position, indicating the application of downward pressure on the chinrest to stabilise the instrument during playing (Paper III). The high static muscle activity, around 10% MVE for the right SCM, did not change with the novel EC, which still required pressure on the chinrest (Figure 18). We observed only a 1% change, which we do not consider substantial since we expected a larger change due to the lower muscle activity in the "resting" position (half of the muscle activity), and compared to the left side's muscle activity, which was around 3-5% MVE. Furthermore, an EVA analysis did not reveal prolonged durations of high muscle activity for the right SCM but relatively brief periods of high (10-20%) and low muscle activity (around 5%).

There could be multiple reasons why we did not find a difference between UC and EC. Professional musicians are well-trained to execute specific movement patterns and muscle loads; thus, modifying the chin and shoulder rests may not alter these established motor skills. We did not measure the violin's placement angle, which could have provided further insight into the adjustments made [171]. Measuring the height is just one aspect that can be adjusted on EC; therefore, this measurement reflects only one dimension. The violinists could have repositioned the violin to compensate for the height difference.
Repositioning the violin can have implications beyond the muscles we specifically investigated. Suppose the violin's tilt becomes smaller to the player, along with a more sideward orientation. In that case, it can significantly impact muscle activation and perceived effort in the left forearm [171]. These changes can potentially lead to alterations in overall muscle activity, either increasing or decreasing it, which can consequently influence the overall evaluation of the violin's ergonomic design. While the chinrest may not directly affect the neck and shoulder muscles, it is also important to investigate other muscle groups, as they can impact the violinist's overall performance. Therefore, future research may consider including other muscle groups, such as the left forearm, to assess whether some additional changes or effects may be relevant.
In this project, our goal was to biomechanically modify the head posture, especially the tilting and flexion angles. However, the results of Study III revealed that participants already exhibited a relatively aligned head posture, except for a noticeable head rotation away from the ideal alignment, specifically at an average angle of 15° to the left. Therefore, attempting to directly modify the head alignment with EC would likely yield limited effectiveness. Furthermore, in addition to the lack of significant changes in head alignment, we did not observe substantial alterations in muscle activity either, which was disappointing.

01.01 The general workload levels

In our previous work [60], where musicians played the same music piece with UC, we found that the muscle activity for both UT was above 5% of maximum voluntary contraction in both the "resting" position (holding the instrument for 20 seconds) and the playing position (Table 11). We observed that the left UT had higher muscle activity when supporting the instrument but less when playing (n=18), and this finding was confirmed in Study III (n=38). We found similar workload conditions for the right UT in Study III, with muscle activity above 10% MVE during playing. Generally, we found quite identical static workload conditions across both studies, strengthening our findings' external validity. The APDF also revealed muscle activity above 5% MVE for all muscles in the upper body (Figure 18). Repetitive playing for many hours with muscle activity around or below 5% MVE has been shown to cause pain and fatigue [172]. The length of the period is the real risk factor, and the APDF does not consider the time spent at the static level. However, the EVA analysis for the right SCM showed a mix of short and long durations of low static activity with uninterrupted periods of breaks for both conditions.

Table 11 Workload conditions (muscle activity) across a previous study and study III.

	Resting position Left UT %MVE (95%CI)	Resting position Right UT %MVE (95%CI)	Music piece Left UT %MVE (95%CI)	Music piece Right UT %MVE (95%CI)	Static position Right SCM %MVE (95%CI)	Music piece Right SCM %MVE (95%CI)
Previous study [60]	9.8 (5.4-14.5)	7.1 (4.4-11.4)	8.8 (6.0-11.6)	11.5 (8.2-14.9)	-	-
Study III UC	10.0 (6.5-13.5)	11.7 (8.4-15.0)	7.1 (5.2-8.9)	10.7 (8.3-13.1)	4.9 (3.7-6.1)	10.7 (8.3-13.1)
EC	8.6 (6.0-11.2)	11.1 (8.0-14.3)	6.4 (4.9-8.0)	10.4 (8.9-12.0)	4.7 (3.4-5.9)	9.7 (7.5-12.0)

UT: upper trapezius, SCM: Sternocleidomastoideus, UC: usual chinrest and shoulder rest, EC: ergonomic chinrest with shoulder rest. CI: confidence interval.

It is important to understand that this project did not focus on fatigue or pain, and the short time frame played and analysed only reflects a few minutes out of a typical working day for musicians [17,18]. However, studies have pointed out that low-level intensity with no interruption can cause pain [173,174]. Despite using EC compared to UC, we did not find a change in the low-intensity level.

17.3 Self-reported versus objective measures

In Study III, we observed a difference between self-reported and objective alignment measures, highlighting the complexity of comparing subjective experiences with objective measures. Violinists reported feeling more aligned with EC, but the objective measurements revealed only minor differences (less head left rotation (3.3°) and more head extension (1.3°)) and no change in lateral head tilting (around 6° left head tilting). Violinists may rely on proprioceptive cues and sensory feedback, leading to a subjective sense of alignment that we might not judge as substantial changes when captured by 3D motion capture technology (Vicon). Minor changes may feel more significant for violinists who have been used to playing in a certain position for many years.

It is also essential to recognise that subjective perception of alignment can be influenced by factors such as self-confidence, body awareness, and psychological states. Attention bias cannot be ruled out because merely trying out a different product can lead participants to perceive a change in their working posture, as it is the focus of the project and a primary motivation for violinists to participate.

Surprisingly, self-reported muscle activity aligned with the objective findings, showing no significant differences between UC and EC. This could be attributed to the experience of violinists in accurately assessing their workload demands due to years of practice.

Furthermore, in Study III, EC scored lower in performance than UC (a 15.5% decrease), and the sound was affected, with many negative comments about the product's design. These factors contribute to the complex interplay that can influence self-perceived outcomes. It is noteworthy that a single usability outcome can significantly impact and modulate the effects of other outcomes within the user experience [175,176].

Violinists develop a close relationship with their instrument over time and become attuned to its characteristics and sound [45]. Changing the chinrest or shoulder rest could have disrupted the established connection, resulting in a decline in performance. Additionally, we only received information about the participants' motivations. Still, a more in-depth investigation into their expectations could have provided insight into their attitude towards testing EC, which can subjectively influence self-perceived outcomes. Another subjective factor is that the visual appearance of EC may have influenced the low-performance score. A study revealed that the appearance of a phone could impact its performance, with an aesthetically appealing design showing better results [176].

The musicians demonstrated an ability to distinguish between EC and UC audio files beyond chance levels, indicating their advanced musical training in sound and timbre perception. The lower "quality of performance" score for EC and UC may explain why violinists could distinguish between the two conditions. Previous research has shown that timbre can be altered by different shoulder rests, although the variation depends on the violin [87]. This implies that modifying the chinrest and shoulder rest, as done in this project, may influence timbre and overall performance quality. In this study, we can't determine whether the shoulder rest or EC may change the perceived sound. Furthermore, only four participants were able to correctly connect the audio file to EC, which also leaves uncertainty about the specific influence of EC on the auditory experience.
The combination of EC and shoulder rest was feasible in Study II. However, Study III received many negative comments about the shoulder rest, citing pain and influence on playing angle. The different usability issues found, such as low performance, maybe more closely connected to using this specific shoulder rest in combination with EC.
Since some violins change the timbre due to shoulder rest [87], some violinists also prefer different shoulder rests. Another shoulder rest might influence the usability outcome; however, the Kun shoulder rest is a commonly used brand among many of the violinists being tested (Paper IV) and was also found feasible in Study II.

17.4 Sample Size Considerations

The feasibility study included a small sample size of six participants, while the cross-over study expanded the sample to 38 participants. It is important to acknowledge the limitations of a small sample size, such as reduced statistical power and potential challenges in generalising the findings to a larger population [165]. However, despite the small sample size in Study II, both studies consistently revealed that EC did not effectively change head posture compared to participants' usual chinrest and shoulder rest (UC).

We used Study II to estimate the sample size for the larger Study III. Using feasibility studies for estimating sample size calculations is not recommended due to the limited number of participants and a different focus [165]. However, in this project, it was necessary due to the lack of literature in this area. The data used to estimate the sample size was dichotomous, which reduces the available information for analysis as it only provides two categories/outcomes. Therefore, it presents certain risks and uncertainties and may not fully capture the complexity and nuances of the variables being studied. This increases the risk of a Type II error, also known as a false negative, which occurs when a study fails to detect a significant effect or relationship that exists in the population. The small sample size limits the study's statistical power, making detecting actual effects or associations more challenging. Therefore, it is important to interpret the results with caution and acknowledge the possibility of potential false negatives due to the limited sample size. However, the consistent directionality of the results from both Study II and III, including the continuous data results, strengthens our confidence in the findings despite the small sample size.

Given the limitations of the sample size, it is recommended that future research be conducted with larger sample sizes based on continuous data to comprehensively investigate the efficacy of the ergonomic product and enhance the robustness of the evidence. By expanding the sample, a more extensive population representation can be achieved, thereby improving the generalisability of the findings. However, it is noteworthy that despite the selected sample of pain-free musicians, this group still constituted a substantial portion, approximately 20% (n=28), of violinists holding permanent contracts in Denmark, signifying a considerable representation within this population.

In summary, while the small sample size in the feasibility study warrants caution in generalising the effect results, the consistent findings across both studies (II and III) support the evidence that EC lacks impact on changing the head kinematics and muscle activity compared to UC.

Furthermore, the feasibility results all point in the same direction: WSR is less feasible for violinists playing with a shoulder rest than SR. WSR showed low compliance and more negative feedback than SR. One study also finds that SR is evaluated better in comfort than WSR or a high shoulder rest, supporting our findings [111].

17.5 Usability

The concept of usability originates from the field of human-computer interaction (HCI) and user-centered design [177]. Overall, usability is crucial in optimising product and system design and functionality (user-friendliness) to effectively meet users' needs and expectations.

As described in the introduction, we have used the definition of usability from the ISO standard, which focuses on users using a product to achieve specified goals with effectiveness, efficiency and satisfaction [101,177]. This dissertation is the first to focus on the user experience, including the usability of an ergonomic product among musicians. Other studies [111,116] that have examined comfort-related aspects have primarily focused on the biomechanical factors, utilising specially designed products such as a laboratory-designed chinrest rather than evaluating a specific ergonomic product (EC) already produced.

Usability is a widely discussed term which is also context-dependent and influenced by the interaction with the surroundings [178]. Therefore, it was challenging to find valid questionnaires that could capture the essential aspects in the specific context of our study. When searching for valid questionnaires, most focused on technology [179] or website usability [180]. Many questionnaires are not developed in Danish, or the construct is designed to be used at the end of the test and not during a testing period.

One huge limitation of this PhD project is the many self-constructed none-validated questions. However, using self-constructed questions tailored to this context and measured usability outcomes over time can be considered a strength because the measured usability outcome is relevant. We also detected that many of the usability issues changed over time. The usability outcomes we found relevant are mentioned in the literature and might not cover all relevant topics. This could have been investigated deeper among the participants.

In this project, we gained insight into key aspects such as confidence, performance (effectiveness), and adjustments (efficiency). To assess overall usability satisfaction, we measured various factors, including emotions, comfort, design, and sound. Some of these factors are well-known to collectively impact the user experience [181].

A questionnaire called System Usability Scale (SUS) [182] (Figure 23) is often used to evaluate electronic systems and is a quick tool with few items. Items four and six may need to be rephrased to be relevant in this specific context and the scale had to be translated.

However, many of the items in this questionnaire are like some of the topics written in the diary, such as the complexity of using EC (Figure 19). Using this questionnaire would have allowed everyone to address different issues they might not have considered when just answering the open-ended question in the diary.

The System Usability Scale
Standard Version

		Strongly Disagree 1	2	3	4	Strongly Agree 5
1	I think that I would like to use this system frequently.	O	O	O	O	O
2	I found the system unnecessarily complex.	O	O	O	O	O
3	I thought the system was easy to use.	O	O	O	O	O
4	I think that I would need the support of a technical person to be able to use this system.	O	O	O	O	O
5	I found the various functions in this system were well integrated.	O	O	O	O	O
6	I thought there was too much inconsistency in this system.	O	O	O	O	O
7	I would imagine that most people would learn to use this system very quickly.	O	O	O	O	O
8	I found the system very awkward to use.	O	O	O	O	O
9	I felt very confident using the system.	O	O	O	O	O
10	I needed to learn a lot of things before I could get going with this system.	O	O	O	O	O

Figure 23 System usability scale with ten items.

Judging the ergonomic suitability of a product among violinists typically occurs within minutes, hours, or a few days (Paper IV). Assessing the violinist's initial impression of the product and observing their perspective after a few days can provide insight into their decision-making process [183]. Another aspect worth discussing is measuring satisfaction, which other people can influence. Many standardised questionnaires are not well-suited for the context of musicians. In our study, we employed open-ended and closed questions regarding the participant's willingness to continue using the product as acceptance measures. However, another widely used question that reflects satisfaction and acceptance could have offered an alternative perspective: *"Would you recommend this xx to a friend"*" [184]. Answering this question could indicate satisfaction and willingness to vouch for the product, as participants put their own 'reputation' on the line when recommending it to others. However, it should be noted that some participants (37%) who expressed their intention to continue using the product might have given a positive answer to that question. As the principal author of this dissertation, I observed that violinists who liked the product (EC) also recommended it to others beyond this project's scope.

Creating and validating new usability tools specifically for this population exceeded the scope of our study. However, future research focusing on musicians and validating usability constructs from an ergonomic perspective should be considered. It is important to acknowledge the limitation of this project, as many of the questions were self-constructed rather than based on validated questionnaires. Additionally, having two independent blinded reviewers screen the citations would have enhanced the validity of the themes and the dichotomous categorisation of positive and negative answers instead of relying solely on the primary author to analyse the statements.

An overview study addressing the challenge of measuring usability highlights the importance of considering time as a key element [181]. Measuring usability over time can provide valuable insights into whether initial usability problems or dissatisfaction diminish. In Study II, playing with WSR was deemed unfeasible due to usability issues during the two-week familiarisation period. However, this finding does not imply that using WSR cannot offer other benefits over an extended period. The time required to achieve proficiency in playing with WSR was not feasible within the chosen timeframe.

Furthermore, many of the initial usability problems encountered with EC in Study III changed over the two weeks, with most positive comments reflecting an improvement over time. Participants providing feedback in a diary or logbook may focus more on negative aspects as they stand out immediately and are commonly referred to as 'usability flaws' [185]. Over the two weeks, we observed a shift in comments as the violinists became more accustomed to the adjustment, experiencing fewer problems.

Additionally, our findings indicate that violinists adjusted their height to their neck length better with UC than with EC. We did not investigate this, but it may be due to difficulty selecting between the different heights (four posts) (Figure 5).

Whether the familiarisation period should have been shorter to align with their typical decision-making timeframe (days, as mentioned in Paper IV) can be debated. However, shortening the familiarisation period would likely not have revealed the changes in usability outcomes, considering that over half of the participants (n=29) found the duration appropriate, according to Paper IV. The length of the familiarisation period and the resulting changes in usability outcomes may have influenced the 37% of participants who expressed a desire to continue. It is important to note that this PhD project did not focus on identifying the specific usability outcomes that may have influenced participants' decision to continue with the product. This aspect could be the subject of future studies specifically designed to address this question.

Furthermore, acceptability refers to how well a product meets the users' needs, preferences, and expectations. Another factor that can influence acceptability is its cost [122,186]. In Study I, II and III, the users were provided with the product for free. However, the cost of a product may lead to a lower level of acceptability and a negative user experience if the cost exceeds what the participants consider reasonable. Including this aspect would be relevant in future projects.

17.6 Familiarisation period

A familiarisation period was provided to all participants before the crossover design, during which they played with the UC and EC in a randomised order.

One of the strengths of having a two-week familiarisation period with the EC is that it allows violinists sufficient time to adjust the product to their playing style. Additionally, learning a new and specific perturbation can take time, and the two-week period will enable participants to play and become accustomed to it [187,188]. Incorporating the familiarisation period before the test day was necessary due to using objective measurement methods such as EMG, ViMove, and Vicon. Conducting testing on two separate days, one before the familiarisation period and one after, would have introduced potential confounding factors that could impact the comparison of measurement methods. These factors include:

1. Variability among participants, including their baseline levels of fatigue, pain, and muscle condition on the two testing days, as well as their mood and mental states. The time interval between the two days can influence these factors.

2. Contextual factors include room temperature, lighting, and other individuals present during testing. Although a strict protocol was followed, minor changes in these factors could potentially affect the results.

3. The accuracy of the equipment, including electrode placement, skin preparation, signal amplitude and sensitivity, calibration, and other technical considerations.

Furthermore, testing all violinists on two separate days would have increased the risk of dropouts and would have been time-consuming and expensive. A wash-out period was implemented on the test day to minimise the risk of motor adaptation and ensure that the internal model[2] was adjusted to the EC. Previous research has demonstrated that individuals can quickly adapt to an earlier perturbation if they have encountered it before, with the time for adaptation varying from minutes to days or weeks depending on the initial adaptation (savings) [189,190]. It should be noted that all recruited violinists in these studies had played with their UC for many years. We deemed a five-minute wash-out period appropriate based on their extensive experience with the UC and the fact that violinists can quickly adapt between different shoulder rests without affecting the sound [113].

17.7 Diary

When using a diary or logbook and recording the hours of use with the EC, there is a possibility of overestimation, as it may not account for the hours playing with the UC at home. This tendency to overestimate in logbooks has been observed in home training scenarios [191]. Monitoring the use of an ergonomic product without employing a pressure sensor on the chinrest to validate its use can be challenging. Implementing a Wi-Fi sensor for recording usage would be necessary to validate the data, but it would also incur additional costs. To enhance the validity of the data, we encouraged participants to be accurate. We provided them with text message prompts every evening to ensure the correct information was recorded. Participants were also encouraged to provide negative and positive feedback in the diary.

[2] The internal model is a cognitive representation within the brain that combines sensory information with motor commands to anticipate and plan movements in order to achieve a specific goal

17.8 Strength and limitations

Throughout the entire PhD dissertation, various strengths and limitations have been discussed. This section aims to provide an overview of the most significant elements.

One notable strength of the studies is the adherence to recommended guidelines for diverse study designs. The methodological rigour is evident in the high external validity of the outcomes, achieved by carefully considering the implications of each conducted study on subsequent planned studies.
This approach strengthens the methods employed in the final study (III). Furthermore, this study stands out as the first to evaluate the ergonomic product (EC) compared to the 'do-as-usual' approach (UC). By considering typical usage scenarios, the study enhances methodological rigour and increases the real-world applicability of the results, thereby enhancing their generalisability. Detailed descriptions of each study method are provided, promoting transparency and facilitating other researchers' application of these methods.

Multiple data collection methods were employed to ensure a comprehensive evaluation of the ergonomic product. These methods included subjective measures, technical systems, and validated systems. This approach allowed for a thorough examination of the product from various perspectives, enriching the robustness and depth of the study's findings.

Various objective methods were employed, RULA-ViMove and Vicon, each with their respective strengths and weaknesses. RULA and ViMove are more affordable and accessible in different settings. However, RULA lacks a specific focus on neck posture evaluation and relies on subjective measures, while ViMove is based on a technical system. Nonetheless, reliability issues were encountered when accurately measuring rotation angles using the ViMove system. In Study III, Vicon was utilised as a valid system in a clinical setting, but its implementation required significant physical space, time, and resources (trained personnel). Additionally, it is quite expensive to use and implement.

Furthermore, non-validated questions were employed to assess usability outcomes in this context. Nevertheless, the studies could have benefited from incorporating validated questionnaires or drawing inspiration from them, as certain questions might have been applicable in this unique context. By incorporating validated questions, the reliability and validity of the usability assessments would have been enhanced. However, it is important to establish new usability questionnaires targeting this specific context. Moreover, determining the cut point for the level of usage (compliance) in Study II was based on a pragmatic estimation that could have been discussed with a selected group of violinists to ensure a relevant and meaningful cut point.

Another limitation of the studies is that they were conducted in laboratory settings, which may not fully reflect real-world conditions. While the controlled environment allowed for precise measurements, the findings may be less representative of real-world settings. To enhance the external validity of the results, future research should consider including field studies or observational settings that better capture the complexities and variations of everyday situations in which a violinist would use the ergonomic product.

In a real-life setting, violinists often must make compromises when sharing a note stand with another violinist, affecting their sitting position on the chair and their visual contact with the conductor, leading to changes in their body movements [108]. However, when violinists play for many hours at home without these external factors, the setup used in the studies could reflect that environment.

In Study II, we had initially planned to involve a panel of violinists/musicians during the design phase, which would have contributed to a user-centred design approach, addressing the specific needs and challenges using a specific method known as testing EC. However, due to time constraints, the study could not incorporate this valuable perspective and instead relied on experts in this area.

18 Conclusion

This PhD project has contributed new knowledge regarding the feasibility, user experience and effectiveness of using an ergonomic chinrest to biomechanically change head posture and muscle activity compared to the usual chinrest and shoulder rest.
In the overall conclusion, it was determined that this particular ergonomic chinrest proved feasible when used with a low shoulder rest. However, the findings did not reveal substantial changes in head posture or muscle activity compared to the participants' usual chinrest and shoulder rest. This project also identified various usability issues associated with the EC, indicating that this specific EC cannot be recommended as a superior alternative for improving the health of violinists.

Studies I and II shed light on the feasibility of utilising the EC. The results indicated that the EC was feasible when used without baseline pain, accompanied by straightforward and clear instructions, and with a low shoulder rest.
However, Study III disappointingly did not demonstrate substantial changes in head angles or muscle activity compared to UC. Regarding the head angles, it was observed that making significant adjustments to the head posture when participants used UC would have been challenging as their head posture was nearly aligned, with only a 6° left tilting and 1° flexion. The head rotation was the only angle that was not aligned with 18° to the left. No significant changes were found in head angles, and similarly, the upper body muscle activity remained consistently at approximately 5-10% across all muscles. Furthermore, EC presented various usability issues, including lower performance scores, impact on sound quality, and numerous challenges related to pain and adjustment during the two-week familiarisation period. Despite some usability issues, 37% of participants expressed intentions to continue using the EC after the study. The insights gained from user experiences and challenges encountered during the study can provide valuable inputs for the design process of the EC or other ergonomic products developed for violinists.

19 Implications for violinists and future perspectives

19.1 Implications for Violinists

This study represents the first comprehensive investigation comparing a specific ergonomic chinrest (EC) to the usual chinrest (UC) among violinists. The findings have important implications for violinists and the use of ergonomic chinrests. While the aim was to explore the effects of changing posture or reducing muscle activity using an ergonomic chinrest, no significant changes in upper body muscle activity or head posture were observed when comparing the EC to the UC. This suggests that the specific ergonomic chinrest used in this study cannot be recommended as a superior alternative to violinists' usual ergonomic chinrest.

Furthermore, this PhD project has shed light on the limitations of the specific EC in terms of comfort, performance, design satisfaction, and issues related to instructions, product adjustability, and sound. Incorporating this information and considering various human factors that influence the design process will increase the likelihood of successfully meeting the needs of violinists and improving satisfaction. Future studies are needed to investigate which usability outcomes are most important for violinists and have the greatest impact on decision-making.

19.2 Ergonomic Solutions

When searching for an ergonomic product, it remains crucial for violinists to find a solution that enhances playing performance, provides comfort, and maintains sound while minimising the subjective feeling of muscle tension. Allocating sufficient time to make informed decisions about the benefits and challenges of using a particular product can help violinists gain insights into what works best. Maintaining autonomy in decision-making is also significant, as many musicians have limited control over where, when, or how they perform.

Violinists should feel empowered to prioritise their needs and preferences when considering ergonomic solutions, recognising that one size does not fit all. It is essential to find solutions that can support individual violinists' needs, preferences, and playing styles, leading to more successful outcomes and higher satisfaction levels.

19.3 Future Research Directions

Notably, a considerable proportion of participants expressed intentions to continue using the EC after the study, emphasising the importance of investigating and understanding changes in health behaviour among violinists and identifying the necessary factors to enhance their well-being. Further systematic research is needed in this area.

Another perspective for future research is to compare ergonomic solutions among different subgroups, e.g., exploring the outcomes between different age groups, experienced and inexperienced musicians, and participants with and without pain.
It is worth considering that participants without pain may have already selected optimal ergonomic solutions, resulting in similar head alignment and muscle activity patterns compared to this specific EC. By examining these subgroups, a more comprehensive understanding can be gained regarding the potential impact of ergonomic interventions on different populations of musicians.
Additionally, exploring other innovative ergonomic solutions beyond adjustable chinrests, such as dynamic, ergonomic equipment or specialised equipment designed to hold the instrument and alleviate the need for manual support, may present alternative approaches to reducing the overall workload. Biofeedback is another pedagogical tool shown to decrease unwanted muscle tension [192], which could reduce the tension found in the right m. sternocleidomastoideus.
However, this project provides preliminary evidence that ergonomic chin or shoulder rests may not be the most effective tool for changing workload demands. Devoting substantial time to searching for an optimal position with an ergonomic product does not guarantee pain reduction. The ideal biomechanical setup on the violin is still unknown, and the evidence linking pain to optimal or suboptimal posture is being questioned [193].
A recent study found that the sustained duration spent in a specific static posture can contribute to increased pain levels, regardless of whether the posture is aligned [194]. We did

not observe any changes in muscle activity; instead, we found a consistent muscle activity pattern in the final study.

Therefore, another potential solution to address workload demands is to investigate the effectiveness of micro-breaks or incorporate active and specific training during rehearsals which could also be a solution to address workload demands. Incorporating micro-breaks during rehearsals may effectively disrupt prolonged periods of static contractions, leading to improved recovery from metabolic changes in the muscles and reduced pain and fatigue [195].

Strengthening the muscles involved in violin playing can reduce workload and potentially alleviate pain. Previous studies have demonstrated that strength training targeting musicians' most exposed muscle groups can effectively decrease pain levels [196,197]. The efficacy of utilising strength training to alleviate pain has been established in alternative occupational settings [198], highlighting that even as little as two minutes of exercise per day can positively impact pain and muscle strength [199].

Moreover, it is important to recognise that various factors beyond posture and muscle activity alone influence neck and shoulder pain. Further investigation of other risk factors such as age, work environment, stress management, and performance anxiety are crucial to safeguard musicians' health.

19.4 Economic and Societal Implications

Taking a broader perspective, it is essential to consider the economic and societal implications of musicians' health. Despite significant investments of time and resources in their education, there is limited focus on musicians' health and preventive measures to address their high reported pain rates. The financial consequences of not maintaining a sustained and healthy working life can impact individual musicians and society. Therefore, it is vital to explore the economic implications to underscore the significance of musicians' health, not only in terms of societal impacts (e.g., productivity loss, sickness absence, and musicians leaving the profession) but also to ensure that individuals feel valued within society. By supporting a healthy work-life culture for those who bring joy to others through their music, we can emphasise the importance of musicians' health.

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"It is not the music that is important. It is the notes you cannot hear that matter.

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22 Appendix

Appendix A: Overview over violinists in Denmark

Appendix B: Overview of the search and findings of shoulder rest

Appendix C: Overview of the search and findings of chinrest

Appendix D: Recruitment letter

22.1 Appendix A: Overview of violinists in Denmark

The number of violinists used in a symphony orchestra production depends on the repertoire, with a maximum of 30 violinists comprising 16 and 14 first and second violins, respectively. On average, approximately 20 violinists are employed in a production, such as a Mahler or Brahms composition, by one of Denmark's largest symphony orchestras, the Danish National Symphony Orchestra. Unfortunately, data on the number of individuals employed in Denmark with a permanent contract in a symphony orchestra is unavailable. However, a short phone survey conducted in 2021 with all seven of the country's orchestras revealed that 179 violinists hold permanent positions. While this number is relatively small for Denmark, the classical music industry is more extensive globally.

Overview of all symphony orchestras in Denmark and the number of violinists with a permanent contract in 2021.

Orchestras in Denmark	**Violinists with a contract in 2021**
Sønderborg symphony orchestra	19
Aalborg symphony orchestra	19
Århus symphony orchestra	22
Odense symphony orchestra	22
Copenhagen Phil	21
The Royal Danish orchestra	35
Danish National symphony orchestra	41
Total	**179**

22.2 Appendix B: Overview of the search and findings of shoulder rest

Shoulder rest search	
Brand name	**Model name**
Resonans	1. medium
Wolf	1. Forte secondo 2. Standard Secondo 3. Forte Primo 4. Standard Primo 5. Standard Primo-fixed height 6. Super Flexible
Kun	1. Original 2. Voce 3. Bravo 4. Collapsible 5. Super 6. Solo
Pirastro	1. KorfkerRest 2. KorfkerRest Luna 3. Model 2
Bon Musica	1. 1/16 2. original
Mach One	1. Synthetic 2. standard
Belvelin Fiolosofen	-
Violin Lady	-
Arvada	-
Fom Standard Plastic	1. Fom K60
Hidersine Oxbury	
Viva la musica	1. Flex 2. Diamond 3. Artist 4. Standard/orginal 5. Compact 6. Light
Everest	1. standard 2. titanium

	3. Collapsible
Wittner	1. Isny
Muco	-
Markov	-
Artino	1. Comfort 2. Sound model
Dolfinos	-
Efel	1. Plus
Belvelin	-
Playonair	1. Deluxe 2. Crescent
Petz	-
Franz Sandner	-
Empire	1. Adjustable
Performa Padauk/Thermoplastic	-
Fiddlerman	-
Beepa J&J	-
Vanoga	-
AMZZ	-
NANYI	-
MIATIN	-

The table shows the overview of the findings of the search for shoulder rest.

22.3 Appendix C: Overview of the search and findings of chinrest

Chinrest: **Brand name and model**	Material	No adjustments	Height adjustments	Tilt adjustment	Placement	Additional adjustments
Wittner 1.Zuerich 2.Side 3.Center 4.Augsburg	Composite material	2 + 3	1+4	1+4		
Guarneru Köln	Wood	x				
Arvada VCR44	Wood	x				
Goetz/ Götz 1.Hamburg 2.Stüber 3. New Flesch Style 4. Old Flesch 5. Guarneri 6. Stradivari 6. Slim 7. Kaufmann 8. Jacob 9. Milano 10.Conrad	Wood	1-13				

11.Flat 12.Varga 13.Berber 14.Leipzig 15.Schulze-Priska 16.Morawetz 17. Veit Jacob						
Wolf 1.Stradivari 2.Guarneri 3.Maestro 4.Special 5.Classic 6.Maestrino	1-2: Wood 3: Leather (Napa)	1-2	3-6			
SAS	Wood		x*	x		
Viva la Musica 1.Augustin 3D adjustable	Plastic		x	x		x
Gewa 1.Guarneri 2.Berber/ohrenform 3.Varga 4.Flat 5.Wendling 6.Stüber 7.Hubermann	1-7 and 9-14: Wood 8+15: Wood or plastic 16: Plastic	1-16				

8.Teka 9.Paganini 10.Strobel 11.Kantuscher 12.Flesch 13.Morawetz 14.Wiener 15.Dresden 16.Mulko 17.Neukölln 18.Vermeer 19.Hill						
Berdani	Paper and resin	x				
Roth & Junius CR 1.Vermeer 2.Overal Small 3.Hill 4.Beran 5.Wendling 6.Guarneri 7.New Flesch 8.Old Flesch 9.Wiener 10.Kaufmann 11.Morawetz	Wood	1-20				

12.Hollywood 13.Teka 14.Dresden 15.Stuber 16.PVS 17.Varga 18.Stradivari 19.Oval 20.Schmidt						
STRADEPT Jujube 1.Guarneri	Wood	x				
Edu	Wood	x				
Zitsman	Wood	x				
The Impressionist	Plastic					x (cushion on the top of a chinrest which shapes after the jaw)
Gelrest						x
Stuber model	Wood	x				
Extra Tall 1.Hamburg 2.Teka 3.Gyarneri 4.Flesch	Wood		x*			

Holstein comfort	Wood	x				
Huberman	Wood	x				
Kréddle	Plastic		x	x	x	x-rotation
Wave	Wood		x*			
Dolfinos	Plastic		x			
MUSANUS 3D chin rest	Wood		x	x		
Flesch 1. standard 2.Flat 3.Heigh adjustable	Wood	1-2	3			
Adjustable Pitch	Wood			x		

The table displays the results of a search conducted in 2020 and 2023 for various models of chinrests on different web pages[3]. Multiple types of chinrests are available for violins, each with unique designs and features. For each model, information about material and adjustments are given either with the model number or a mark x. *The height of a chinrest cannot be adjusted after purchase. It is necessary to select the appropriate height at the time of purchase to ensure that the height received is the correct one. The following section will explain the different models to clarify their respective functions. The Flesch chinrest is named after Hungarian violinist Carl Flesch and has a cupped shape centered over the tailpiece, like Spohr's original design. The Guarneri chinrest is named after a distinguished family of luthiers from Cremona, Italy. It is attached directly over the tailpiece but with the cup to the left of the tailpiece. This design claims to protect the

[3] Shar Music (https://www.sharmusic.com/), Thomann (https://www.thomann.de/), Fiddlershop (https://fiddlershop.com/), Johnson String Instrument (https://www.johnsonstring.com/), Violin Pros (https://www.violinpros.com/), StringWorks (https://www.stringworks.com/), The Violin Shop (https://www.theviolinshop.com/), Southwest Strings (https://www.swstrings.com/), The Sound Post (https://www.thesoundpost.com/), Gear4music (https://www.gear4music.se/), Danguitar, Denmark (https://www.danguitar.dk/), Hertzmusik (https://www.hertzmusic.dk) and Musikinstrumenter (https://musikinstrumenter.net/)

instrument and provide a more comfortable alignment for most players. The Dresden chinrest is mounted on the left side of the violin and has a contoured cup for the chin, while the Kaufman chinrest, also mounted on the left side, has a flatter cup compared to the Dresden. Finally, the Morawetz chinrest, also mounted on the left side, has a pronounced lip at the front of the chin cup. The Teka model is invented to be a higher chinrest than other models.

22.4 Appendix D: Recruitment letter

Violinister fra hele landet søges til unikt forskningsprojekt

Har du nogensinde været interesseret i at ændre dit hagebræt eller din skulderstøtte for at opnå en bedre arbejdsstilling? Så læs videre:

Du kan deltage i dette forsøg, hvis du:

Er professionel violinist

Er over 18 år

Har tilladelse til at ændre hagebrættet på den violin, du spiller på

Generelt er sund og rask og kan spille på dit instrument uden væsentlige problemer

Ved telefonisk forundersøgelse kan bekræfte, at der ikke er andre forhold, som forhindrer din deltagelse

Center for Musikersundhed søger professionelle klassiske violinister i hele Danmark, som har interesse i at undersøge et ergonomisk hagebræt for i fremtiden at kunne give mere kvalificeret vejledning om arbejdsstillinger.

Formål
Vi vil undersøge, hvordan en ergonomisk ændring kan påvirke den måde, du bevæger dig på, når du spiller. Derudover vil vi teste, om den ergonomiske ændring påvirker lyden fra dit instrument, og hvordan du performer. Formålet med studiet er at undersøge, om den udvalgte ergonomiske løsninger kan anvendes af violinister til at forebygge skulder- og nakkegener.

Din deltagelse
Din deltagelse vil indebære, at du skal afprøve et hagebræt kaldet Kréddle. Du skal afsætte 4 timer til at blive testet på Syddansk Universitet i Odense på en dag, der passer dig. Derudover skal du have mulighed for i en periode på 14 dage op til testdagen at anvende Kréddle, når du spiller, for at blive fortrolig med det, inden du bliver testet. Det er altså ikke meningen, at du skal udskifte hagebrættet permanent, men blot afprøve denne løsning i en periode. Du vil modtage Kréddle hagebrættet samt en skulderstøtte sammen med en videoinstruktion.

Honorar
Hvis du er interesseret, kan du beholde det Kréddle hagebræt, som du har afprøvet. Kréddle hagebrættet har en værdi af ca. 650 kr.

Hvorfor deltage
Du vil få en unik mulighed for at lære mere om din arbejdsstilling, og om hvordan en ergonomisk ændring med et hagebræt kan påvirke din arbejdsstilling. Din deltagelse kan bidrage til værdifuld viden i forhold til behandling, undervisning og vejledning af arbejdsstillinger, der kan fremme det sunde musikerliv for den enkelte.

Har du lyst til at høre mere eller deltage i projektet, så kontakt mig på tlf. 65504274 eller mail smann@health.sdu.dk

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23 Papers

Paper I

Medical Problems of Performing Artists

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Preliminary Feasibility and Acceptability Examination of Using a Novel Ergonomic Chinrest with a Low Shoulder Rest by a Viola Player: Case Report

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Conflict of interest

"The authors declare that they have no conflict of interest."

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Prior presentation

Had a poster presentation in Oslo at Musicians' and Performing Artists' Health and Performance – Integrating Body and Mind the 22nd of September 2022 with the title: A viola player's experienced challenges due to chinrest-related altered neck position: a case report.

Abstract

Introduction

High-string players, like violinists and violists, are prone to neck problems. One factor can be their body posture, with often a rotated and flexed neck position with their jaw placed on a flat chinrest.

The Kréddle chinrest (EC) was specifically designed to promote a more neutral neck position and prevent musculoskeletal problems among high-string players. This case report aims to evaluate the preliminary feasibility and acceptability of using the EC, with a low shoulder rest, in a pain-free professional high-string player. A secondary aim was to register newly developed pain and fatigue.

Methods

A 32-year-old professional viola player was instructed to use the EC for most of her playing time during a six-week trial period. Outcome measures such as compliance (% of use out of total playing time the last seven days), performance, comfort and acceptability were assessed at baseline, and at the end of each trial week. The Rapid Upper Limb Assessment tool was used to evaluate the body posture at baseline when using the EC versus her own chinrest and shoulder rest.

Results

The initial trial period was interrupted after two days due to pain. A second six-week period was completed. While compliance was high, and there was positive feedback on how EC affected her performance and comfort while holding the instrument, the case report identified a challenge with the complex instruction material, which made it difficult to install and adjust the product. The viola player was positive towards using EC in the end despite pain and fatigue during the trial period.

Conclusion

This is the first case report evaluating individual challenges related to using an EC. Future studies with larger sample sizes and clearer instructions are warranted to further assess the feasibility and benefits of EC in promoting a pain-free and comfortable playing experience.

1. Introduction

Both the violin and viola are distinctive and elegant instruments but playing them requires musicians to adopt awkward body postures that can lead to playing-related musculoskeletal disorders (PRMD) due to repetitive movements [1]. Musicians are known to experience PRMD [2]. Numerous studies confirm that high-string players (violin and viola players) are particularly prone to neck, back, and upper extremity issues [1,3–5], with incidence rates ranging from 64.1% to 90% each year [6]. Specifically, among full-time professional high-string players, it was found that 70.8% experienced neck pain, and 75.0% had impaired range of neck motion [7]. In severe cases, these complaints can even end a musician's career [8].

While the shape of the instruments is fixed, the shoulder rest (attached to the bottom of the instrument's body) and the chinrest (on the upper side of it) can be adjusted or replaced to improve playing technique and instrument grip. However, there is limited evidence on the effectiveness of such equipment in preventing PRMD [9], and advice on how to use them is often given by violin teachers or luthiers based on anecdotal evidence or tradition. Louis Spohr invented the original chinrest in the early nineteenth century, and a flat-designed chinrest is still widely used today in combination with various shoulder rest [9]. There are a variety of chin and shoulder rests designed to give comfort and adjustability for players of different sizes and shapes. However, a recent study found that a higher chinrest and lower shoulder rest may reduce upper body muscle activity and improve neck position [10]. Aligned neck posture with less chin pressure may allow longer playing hours before the occurrence of fatigue.

An ergonomic adjustable chinrest (EC) called Kréddle was developed to improve neck and body position to prevent PRMD. It was found to be the only fully adaptable chinrest to accommodate players of different sizes and playing styles without needing custom-made options (figure 1) [11]. Many high strings who suffered from PRMD or injuries have found many positive effects of using the EC [11]. However, the reception of the chinrest as preventive ergonomic equipment by a string player without PRMD is a crucial aspect to consider. In the end, any equipment designed to prevent injuries should be user-friendly and easy to use. Nonetheless, it's worth noting that musicians with PRMD may be more inclined to explore new solutions, even if they initially pose challenges [12].

The primary aim was to investigate the preliminary feasibility and acceptability of using EC with a low shoulder rest in a professional high-string player without any current PRMD. Furthermore, as a secondary aim, any newly developed pain and fatigue will be registered throughout the six-week period. This will provide insight into a first-time user's experience with EC.

Figure 1 displays the EC with the low shoulder rest.

1.1. Case presentation

The chosen viola player was a 32-year-old female with a permanent contract in a symphony orchestra. She started playing the violin at 7 years of age and changed to the viola at 17. She plays an average of 31 hours per week, rehearsals and concerts included.
The case participant was selected based on being representative of a high-string player that had never experienced using another chinrest than a standard flat chinrest, was professional and employed in a symphony orchestra, and had no previous trauma to the neck, shoulder or arms. The participant was recruited through networking and word of mouth. Due to the limited availability of professional string players in Denmark and the requirement for participants in the forthcoming studies, we made the decision to enlist only a single viola player. The Regional Scientific Ethics Committee reviewed and approved the study procedure under project id: S-20182000-90. Written consent was signed in accordance with the Declaration of Helsinki. Description of study and dissemination of results followed the case-report guidelines (CARE) [13].

2. Clinical findings

At the initial phone call for inclusion, the case reported no PRMD. However, during the introduction meeting, the case experienced a constant headache with a pain score of 6 for the neck and 0 for the upper back, as rated on an 11-point numeric pain rating scale (NRS) ranging from 0 (no pain) to 10 (worst imaginable pain). The case expressed the reason for the pain because of playing on a new and larger viola. Despite the pain, the case wanted to continue and start the trial period. The viola player's body posture was evaluated by using the Rapid Upper Limb Assessment (RULA) while playing. This is an objective and easy screening tool developed to evaluate risk factors of the exposure (load requirements on the upper body) of the individual worker while doing a task that may be associated with PRMD in the upper limbs [14]. This examination was done by a physiotherapist trained to use the tool. The results are given as a total score sum between 1 and 7; 1-2 concluding an acceptable working posture, 3-4 suggestions to start investigating different postural changes, 5-6 indicating that postural change is needed soon, and ≥7 that postural changes have to be implemented immediately) [14]. A self-chosen except Bach's Cello Suite no.3 in C major, the prelude was played using her normal chinrest and shoulder rest. The RULA-score was 5-6, indicating a risk of PRMD that should be lowered soon by a change of working posture.

3. Intervention

The case underwent a six-week trial period during which she was instructed to use the EC for most of her playing time. The case received information on installing, adjusting, and playing with EC, including watching nine instructional videos and reading an information sheet [11]. Additionally, guidance was given on maintaining proper head alignment, emphasising the avoidance of lateral tilting or prolonged rotation of the head.

4. Outcome measures

Outcome measures were assessed at baseline, and at the end of each trial week until the end of the six-week trial period. RULA was used only at baseline to evaluate the case body posture after attaching the EC, and a questionnaire was filled out every week, including the following listed questions:

1. Compliance (usage behaviour). *"How much have you played with EC out of total playing time in the last seven days".* Compliance with EC was measured on a scale of 0% (no use), 1-24%, 25-49%, 50-74%, 75-99%, and 100%. Full compliance was defined as using EC for at least 75%-99% or 100% of any given week.

2. Performance and comfort. Two specific questions about EC were answered: 1) "*Does the chinrest affect how you play in a positive or negative direction?"* And 2) "*Do you feel a difference in how you hold your instrument, in a positive or negative direction?"* Both questions were answered by scoring on a 5-point Likert scale (1 positive to 5 negative).

3. Acceptability. Every week the case was asked if she preferred her own chinrest by answering “*yes*”, “*no*”, or “*don’t know*”.

For the secondary aim pain intensity and fatigue were asked using an 11-point numeric pain rating scale (NRS ranging from 0=no pain/fatigue at all to 10=worst imaginary pain/ worst possible fatigue).

5. Follow-up and outcomes:

During the introduction meeting, the case encountered difficulty installing the EC despite the instructions. Subsequently, a one-hour online consultation was conducted with the EC developer, providing information on adjusting the height and making individual adjustments using the EC. The primary goal was to achieve close contact with the collarbone while maintaining proper neck alignment and relaxed neck and shoulder muscles. After determining the appropriate height, adjustments were made to the chinrest while ensuring a well-aligned neck posture until a comfortable setting was achieved. Following the online consultation, the case evaluated her experience with the comprehensibility of the instruction, stating, *“It was really good to have the video session with him (developer). I didn’t really see the point before we met him and talked to him and heard him explain his vision for this. And also, the way he instructed me, it was simpler than what we had figured out on the website.”* The RULA score for neck, trunk, and leg improved from 5 to 4 due to a more ergonomic neck position (neck score changed from 3 to 2) but did not affect the total RULA score of 5-6.

The viola player underwent two trial periods using EC. The first trial started in January 2019 but was halted after two days due to a constant headache and an experience of limited head movement to the left, with the jaw positioned too high. The case returned for the second trial period in March 2019 with no neck or upper back pain after a break from playing with EC for 1.5 month. After receiving advice from the product developer again, she relocated the shoulder rest at a further angle from the collarbone, resulting in a lower overall height under the left jaw. The player selected the shortest height out of four options and could not further lower her typical shoulder rest. A timeline of the trial periods is shown in Figure 2.

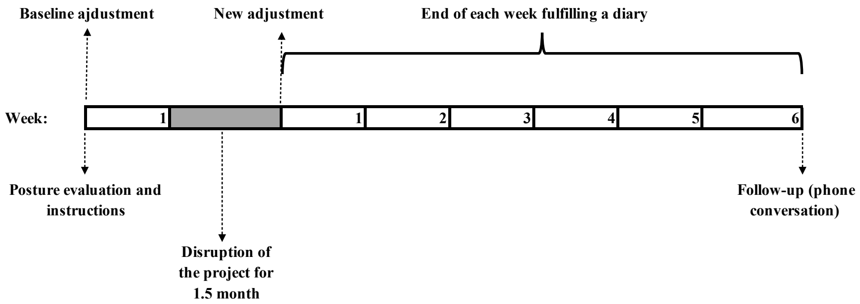

Figure 2 Timeline of events during a 6-weeks period playing with the EC; a first trial period that was disrupted was followed by a second trial period including all six weeks.

In this case, the participant reported three weeks of 100% compliance and one week of 75%-99% compliance. However, during week three, the usage of EC was reported to be less than 50% (25-49%) of playing time, as the case also played on a viola with a flat chinrest that week. Although the usage of EC during week six was not initially reported, the case retrospectively stated that she used EC 100% during that week after the trial period.

Her mean playing time per week for the five weeks was 20 hours, 11 hours less than she had reported as her usual playing time per week.

Figure 3 shows that the viola player at the end of the six-week period positively impacted instrument holding without interfering with her playing performance. The case preferred her own chinrest during the first five weeks but was unsure in the final week.

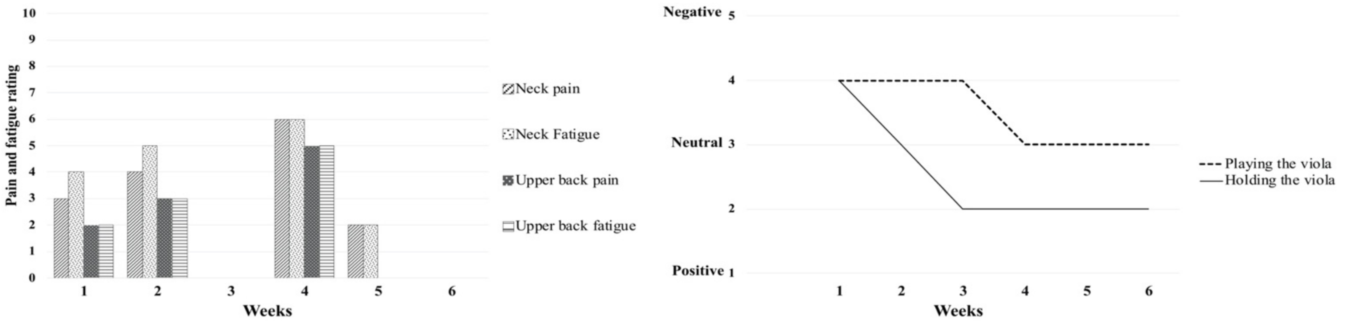

Figure 24 To the left is shown the impact on playing and holding the instrument with the Kréddle scored from 5 (negative) to 1 (positive) during the six weeks. To the right, the pain and fatigue rating during the six weeks regarding experienced trouble/fatigue in the neck and upper back within the last seven days.

A diary entry between weeks three and four recorded that the player was "less optimistic about using EC due to a restrictive and unnatural body posture that limited movement to just one position". She wrote, *"the body posture might be theoretically correct and good-looking, but it was uncomfortable and reduced the performance quality"*. She also wrote that based on tension, she started to take painkillers. In the diary, she reported trouble (ache, pain or discomfort) in the last seven days [15], which showed increased upper back and neck trouble during the trial period and less/none in weeks five and six (Figure 3). This was quite similar for fatigue ratings. In week six, she forgot to report any trouble and fatigue, but on the phone, she said that she had not experienced any of them that week.

In the follow-up phone call, the case expressed a positive attitude towards using EC in the future and evaluated her challenges in the beginning as being challenges related to habit change.

6. Discussion

This case report evaluated the preliminary feasibility and acceptability of using an EC by a professional viola player without previous experience changing the chinrest over a six-week period. While compliance was high and positive outcomes were observed regarding holding position, performance and product acceptance, the study found that the instruction material was too complex and inadequate to fully understand how to install or adjust the product. Excessive complexity could negatively impact product evaluation and be a barrier to use this product [16,17].

This case report highlighted challenges that can be expected when altering the neck position with EC in a healthy viola player, such as increased neck pain initially. Barriers to successfully implementing changes to prevent PRMD can be a lack of time, communication, and knowledge [18]. The time perspective was not a problem in the second trial, where she played less than usual. The viola player was given information about the EC, had knowledge about the purpose and could communicate directly with the owner of the EC, which she did not do despite difficulties with increasing pain and adjustment issues. Increased communication with the product developer could have resolved issues more quickly and made the adaptation process less challenging, but it may not be realistic in real-life scenarios.

While more violin builders and musicians have tried to improve the supplemental equipment to the instrument, there is no scientific evidence that these design initiatives as EC, will work for all high-string players by lowering muscle load to ease or prevent PRMD. When changing to another chinrest, it should be considered that habit changing takes 18 to 254 days and that challenges are common when changing a habit [19]. So, one should preferably be pain-free and have an adaption period to learn to be comfortable with the new body position.

Several studies have explored the biomechanics of shoulder rests [10,20–22], while fewer studies have focused on chinrests [23,24]. This case study provided valuable insights for testing the EC with different setting in a larger feasibility study [25] and later with a control group [26], and yielded the following implications: 1) easy-to-follow instructions, 2) information about a possibility of an increase in pain in the trial period, 3) having a period with fewer playing hours to adapt to the new product, and 4) having regular measurements (every day) to obtain complete data.

6.1. Limitations

While this case study highlights the experience of one individual who experienced pain and fatigue during the six-week trial period, caution should be exercised in interpreting the specific reasons for the observed pain. Several factors, such as increased playing hours or the use of a larger instrument, may have influenced the pain experienced by the participant [27,28]. It is noteworthy that the case actually played fewer hours (11 hours less) than usual during this period. Nevertheless, engaging in more challenging and technical musical pieces may lead to increased muscle tension and potentially result in higher levels of pain, even with reduced playing hours [29]. Additionally, for a case study, the absence of a control group limits our ability to compare the outcomes of the intervention and assess the differences between playing with the ergonomic chinrest (EC) and their own setup. Due to the long-term PhD project, there was a risk of including many string players at the initial stage. If they learned about the EC, some might start using it before subsequent studies began, introducing confounding variables. To avoid this and because a case series could have influenced other potential candidates, we opted for a case report to present preliminary findings, which was more feasible and suitable.

Acknowledgements

The Kréddle Company provided an ergonomic chinrest (valued at 90 Euros) and offered test person free advice on product adjustment.

Conflict of interest

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Paper II

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Measuring the usability of a novel ergonomic chinrest during violin playing: A feasibility study

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Abstract.
BACKGROUND: Playing the violin often requires a rotated and lateral flexed neck, leading to potential neck and shoulder problems. An ergonomic chinrest (EC) with or without a shoulder rest (SR or WSR) may enhance neutral neck positioning, but the feasibility of the EC needs to be studied.
OBJECTIVE: Our goal was to evaluate the usability of the EC for a two-week familiarisation period, including aspects such as playing performance, comfort level, and emotional response (e.g., feelings about using the product) among a group of violinists.
METHODS: A one-arm feasibility study was conducted to assess the feasibility of violinists playing with EC every day for two weeks. Six violinists who usually played with SR were included and asked to divide their daily playing time equally between SR and WSR. Feasibility outcomes were measured as adherence (days), compliance (playing hours per day) and usability (5-point Likert scale and open-ended questions). Compliance was achieved with a minimum of 25% playing time.
RESULTS: Daily violin playing with EC showed high adherence of 89.3%. Compliance with the 25% play time criterion was met for SR, but not for WSR. Low playing performance (median 45.8 points difference), long confidence time (two violinists failed to reach a confidence level) and mainly negative feedback (26 out of 33 comments) were found in WSR compared to SR.
CONCLUSIONS: The feasibility of playing WSR was low and negatively impacted playing performance. As a result, a larger-scale study will only evaluate the EC with SR due to greater feasibility.

Keywords: Ergonomics, music, art, neck, work performance, occupational injury

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1. Background

Designing the job to fit the individual worker is a key element in applied ergonomics [1]. In the context of music performance, adherence to ergonomic principles is often constrained by the design limitations of musical instruments, which may necessitate the musician's adaptation to the instrument's design characteristics. Musicians typically prioritise the quality of sound produced by their instrument, with performance-related discomfort perceived as a secondary concern to achieving a desired level of musical excellence [2, 3].

Multiple epidemiological studies have established that musicians from all age groups and playing levels (amateurs, conservatory students and professionals) have a high prevalence of musculoskeletal disorders [4–10]. Both amateur and professional musicians have a one-year prevalence of musculoskeletal disorders ranging from 68%-86%, but despite these disorders, musicians continue to play [7, 9]. Musculoskeletal disorders in musicians can be caused by several biomechanical factors such as body posture, weight and shape of instruments, playing technique, type of music played, duration of play and the use of assistive devices (e.g., specialised chairs, violin chin, and shoulder rests or wind instrument shoulder straps) [11–18].

The violin is the most common instrument in a symphony orchestra [19]. From a biomechanically perspective, violin playing is physically demanding, requiring asynchronous coordination and static and dynamic muscle activity in the forearms depending on the repertoire being played [16]. The upper trapezius showed consistent static muscle activity, even with different musical pieces being performed [20]. A violin player holds the instrument between the left shoulder and mandible to accommodate a freely moving left hand. The left thumb partially supports the neck of the violin and keeps the instrument's weight. Most of the time, while playing, the violinist puts pressure down on the chinrest with the jaw and a left lateral deviation and rotation of the head [21–23]. This may contribute to the greater prevalence of left-side musculoskeletal disorders among violinists compared to other instrument groups [24]. Reducing pressure between the left mandible and shoulder by changing the neck alignment may extend playing hours and prevent fatigue-related complaints [25, 26].

Historically, using chinrest and shoulder rests has been the most common way of adjusting the violin [27]. This equipment is chosen based on anecdotal evidence and traditions and designed without systematic evidence of their effects on muscles and joints. This lack of optimal adjustment may negatively impact musculoskeletal health and playing performance [28]. On most violins, a chinrest is placed to support the player's jaw. A shoulder rest is attached to the bottom of the violin to lift the violin away from the left shoulder, preventing the violin from slipping from the shoulder and assisting with freedom of movement of the left hand up and down the fingerboard. Shoulder rests are commonly height adjustable and come in different shapes, but there is no consensus about their use [29–32]. To date, there is scarce evidence regarding adjusting chin and shoulder rests for best preventing musculoskeletal disorders in violinists. Furthermore, existing evidence is of low methodological quality [33]. One study suggests that a higher chinrest and lower shoulder rest may be the solution for a better neck posture and less muscle activity [34].

An online search for ergonomic equipment for violins in 2020 revealed many options for adjustable shoulder rests but fewer for chinrests. We found no adjustable chinrests that could move following the violinist's head/neck/jaw movements during the performance. As the second best, a search was conducted to identify a chinrest that considered ergonomic principles and was fully adjustable (regarding height, rotation and tilting) to accommodate violinists' neck length, chin placement, and arm length. Although chinrests are available in different heights and shapes, only one fully adjustable ergonomic chinrest (EC) was identified. This chinrest considers many ergonomic principles by being fully adjustable in height and placement (Fig. 1). The novel EC (Kréddle®, Wyoming, US) was designed to gain healthier movement and accommodate a neutral neck position to diminish playing-related pain and tension [35]. This EC was designed to be played without a shoulder rest (WSR) to lower the instrument as close to the collarbone as possible.

A study among 20 violinists evaluated a low shoulder rest as more comfortable than either non- or a high shoulder rest [34]. In Denmark, many violinists are taught to play with a shoulder rest (SR) when they start playing the violin.

The main aim of this study was to assess the feasibility of playing the violin with the EC with or without a low shoulder rest (SR or WSR), evaluated in terms of compliance, adherence and usability, over a two-week familiarisation period. The secondary aim was to explore the variations in lateral neck posture

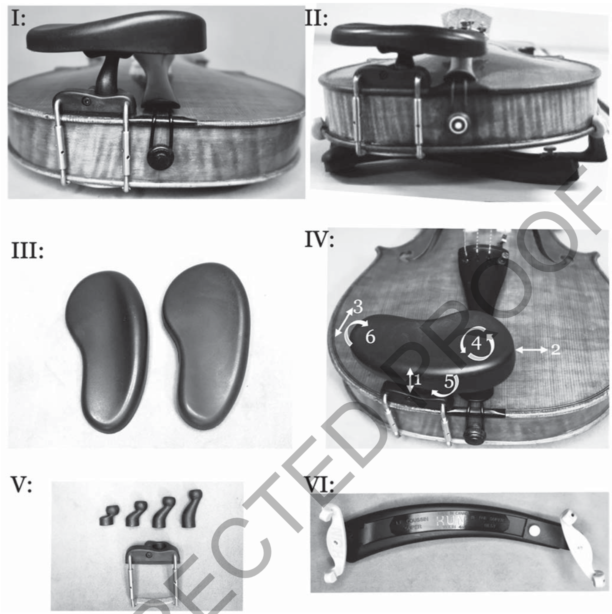


Fig. 1. The picture shows the different settings of EC and different parts of both EC and the shoulder rest. I) WSR (ergonomic chinrest without shoulder rest), II) SR (ergonomic chinrest used with low shoulder rest), III) the chin plates: two different shapes (thicknesses), which can also be seen in pictures I (thicker) and II (thinner), IV) different adjustments: 1) height, 2) lateral movement, 3) backward-forward, 4) rotation, 5) pitch angle and 6) tilt angle, V) the four different post for adjustments of the height including the base attached to the violin, VI) the Super Kun shoulder rest used in picture II (SR) in the lowest setting.

with different chinrest and shoulder rest conditions in the laboratory (with and without the EC). This will enable a statistical power calculation for a larger-scale evaluation trial to assess the effect of EC on neck kinematics.

2. Methods

2.1. Design and procedure

This explorative one-arm feasibility study was conducted to optimise a future research protocol.

Participants were given a two-week familiarisation period to self-adjust the EC to accommodate an aligned neck position without tilting their neck to the left/right side of the violin. This period was followed by a test day in the laboratory, which was a balanced crossover design comparing different playing conditions for the violin with the identified EC: 1) playing the violin with SR, 2) playing the violin WSR, and 3) playing the violin with the individual musician's regular chin and shoulder rest (usual). The trial was retrospectively registered at ClinicalTrials.gov (Identifier: NCT05509465). The reporting in this study adheres to the CONSORT 2010 extension for pilot and feasibility trials [36].

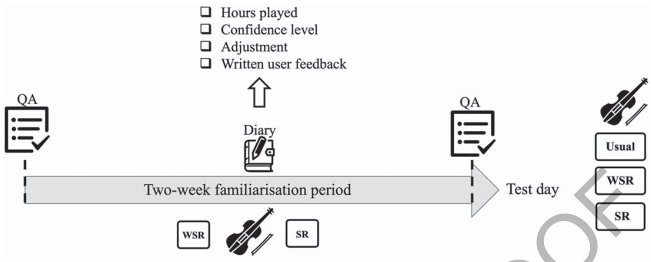


Fig. 2. The overview of the familiarisation period was used to test feasibility. Before and after the two-week familiarisation period, violinists were given a questionnaire (QA). During this period, they had two weeks of unsupervised adjustment and playing time with the ergonomic chinrest (EC). The violinists played half the time without a shoulder rest (WSR) and the other half with a low shoulder rest called Kun (SR). Each day, the violinists recorded their daily playing habits in a diary, which included answering various questions. After two weeks, the violinists participated in a test day, playing with their usual chinrest, shoulder rest, and both WSR and SR. Their lateral neck posture was measured during this test.

The Template for Intervention Description and Replication (TIDieR) [37] was used as a checklist guide when developing the protocol for the familiarisation period (see Appendix).

Each violinist received the EC (Kréddle) and a shoulder rest set in the lowest position (Kun Super rest violin 4/4) via postal delivery and a self-administered two-week diary and music sheets. See Fig. 2 for the two-week familiarisation period. Followingly, each violinist received an email including links to three videos. The videos consisted of a welcome video requesting equal daily playing time between the two conditions (SR and WSR) over the two weeks and two instructional videos informing on EC assembly, adjustment and neck alignment. Participants received a motivational phone call after the first week to encourage compliance. If a violinist was unable to play with EC for more than five consecutive days during the familiarisation period due to illness or interruptions, the period was extended by seven days.

2.2. *Participants and recruitment*

The inclusion criteria required participants to be fluent in Danish or English and trained violinists $\geq$18 years capable of playing the classical protocol repertoire [20]. Exclusion criteria were trauma to the upper cervical spine or upper extremities within the previous year, previous or planned shoulder/neck operation, life-threatening health disorders, a pacemaker or severe eczema on the neck and upper extremities. Further exclusion included violinists with a permanent contract in a Danish symphony orchestra. Symphony orchestra violinists will be recruited for a larger-scale intervention study. Participants were recruited via social media and from a local music conservatory.

2.3. *Outcomes*

During the familiarisation period, a paper diary was used to gather different feasibility information about adherence, compliance and usability.

2.3.1. *Adherence and compliance*

Adherence to the protocol was recorded from the self-administered two-week diary. Each violinist was asked to register daily in their dairy: 1) hours/minutes played with the protocolled conditions, including hours/minutes played with their usual condition. Adherence was counted as the number of days playing with the different protocolled conditions out of the two weeks given.

Compliance for playing with SR and WSR was reached if the violinist managed to play a minimum of 25% of the total playing time in both conditions. Compliance less than 25% defines as a problem to use the condition. Compliance larger than 50% was defined as that violinist favouring one of the conditions, SR or WSR. Considering the novelty of the test protocol, standard guidelines for adherence and compliance could not be identified. The determination of cutpoints was established by the author group and based on a pragmatic estimation of a reasonable level of usage.

2.3.2. Usability

We based our study on the International Organization for Standardization definition of usability focusing on effectiveness, efficiency, and satisfaction [40]. Our analysis revealed insights into the effectiveness of the product in terms of confidence, instruction comprehensibility and performance and its efficiency in terms of adjustments. Additionally, user satisfaction was found to be influenced by a combination of factors, including comfort, sound and emotions [41].

2.3.2.1. Effectiveness: Confidence, instruction comprehensibility and performance. The confidence level was reported daily on a 5-point Likert scale (5 = very confident, 1 = not very confident). 'Very confident' was defined as if the violinist could play the music sheets sent to them also after a break of several days. The quicker participants were able to play the music sheets confidently, the more effective the product was in helping them achieve their goals [42].

The effectiveness of how to assemble, adjust and use EC ('does it work') was previously tested as a single case study (one professional viola player) using the nine videos provided by the Kréddle YouTube channel [43] and the information sheet 'Kréddle tips' from the Kréddle webpage [35]. The viola player was interviewed, and based on this feedback, the nine available videos and instruction sheets were unsuitable for the study. Instead, three new information videos were produced by the lead investigator. The effectiveness of the new videos was tested by asking the violinists if they had enough information about EC to adjust and use it on a simplified nominal scale (3-point expectation score: 'Yes', 'No', 'Don't know'). Specifically, they were asked the question, "Before you started using Kréddle, did you receive enough information to feel well-equipped to use it?"

Performance scores were calculated from the follow-up questionnaire. Some performance questions were modified from the Disabilities of the Arm, Shoulder and Hand questionnaire (DASH), and the score calculation followed the DASH questionnaire [44]. Three questions were used for an overall performance score. "Have you (within the last 14 days)": had difficulty with 1) playing your violin? 2) using your usual technique when playing? 3) playing as well as you would like to? The questions were answered on a 5-point Likert scale from "no" to "impossible". These questions were inspired from the extended version of the Quick Dash questionnaire, which consists of four items for performing artists related to work disabilities [45].

2.3.2.2. Efficiency: Adjustment. Adjustment level was obtained in three categories: 'Yes', 'No', and 'Not yet' daily. The quicker participants were able to find an adjustment that worked, the more efficient the product was in allowing them to achieve their goal with minimal effort or time.

2.3.2.3. Satisfaction: Comfort, sound and emotions. The comfort score was calculation followed the DASH questionnaire similar to the performance score [44]. Five questions were used for the overall comfort score. "How comfortable was (the last 14 days)": 1) playing with SR/WSR, 2) the height of EC (with your chosen adjustment), 3) the configuration of EC that you have chosen, and 4) the size of the EC chin plate? 5) the chinrest surface against your skin? Questions were answered on a 5-point Likert scale from "very comfortable" to "very uncomfortable". Comfort and performance scores were calculated for SR and WSR separately. These questions are inspired from an earlier study that tested comfort using questions about the chinrest, including position, curvature, size, height, etc. [46].

In the last questionnaire before the laboratory test, the violinists had to grade the violin tone and the overall sound experience for SR and WSR compared to their usual condition on a 5-point Likert scale from "very good" to "very poor". These questions were used to evaluate musical performance quality and were modified for this project [47].

Violinists were asked to keep a daily diary to record their experiences using SR or WSR. If they used their usual chin and shoulder rest, they were asked to provide written feedback on why. The feedback was categorised by type and grouped as positive or negative. The qualitative data collected from the diary was analysed using content analysis to extract different themes. The primary author reviewed the responses multiple times to gain familiarity with the data. Subsequently, the themes were classified into positive and negative, and general responses [48].

2.3.3. Secondary outcomes

A web-based questionnaire (SurveyXact) was used to gather baseline information about participants before and after the two-week familiarisation period. The collected data revealed their musculoskeletal trouble in the upper extremities and neck [38], self-rated general health rated from poor to excellent [39], work experience in years and demographic information (age, weight, height, and gender). Furthermore, questions about their rationale for participating in the study and about previous experience with ergonomic chin or shoulder rest.

Although the collected data about neck movement in this study did not have statistical power to detect significant changes, these data were collected to estimate the sample size for a planned larger study. On the test day, all violinists played with all three conditions (SR, WSR and usual) and followed a previously described standardised playing protocol [20]. All played the music piece Mozart's concert in A-major. Their neck movements were detected using two wireless movement sensors (inertial measurement units or IMUs) called ViMove with sampling at 20 Hz: one attached to a hairband placed with the IMUs over the base of the skull (occiput) and the other over the skin of T3 with hypoallergenic double-sided tape. The sensors collect data through an integrated 3D accelerometer, 3D gyroscope and magnetometer, including a Radio Frequency Device, and send the data through a USB to allow for data extraction. This system has shown clinically acceptable agreement compared with the Vicon motion capture system [49].

The data were analysed using ViMove software to calculate the angle of the upper and lower sensors separately relative to the line of gravity. Lateral neck flexion was automatically calculated by ViMove software using the angle displacement of the upper sensor (occiput) relative to the line of gravity.

2.4. Sample size

This feasibility study aimed to test the familiarisation period, procedures, and processes, whereas efficacy testing was not performed [50]. Therefore, no formal sample size calculation was performed. When this study was initiated, we aimed at a sample size of 10-12 as a rule of thumb for a pilot/feasibility study [51].

2.5. Statistical analysis

Descriptive data are presented as the means (standard deviation, SD) or medians (interquartile range, Q1-Q3). We tested all the variables for normality using Shapiro-Wilk, histograms and QQ-plots and found the distribution to be screwed. The Wilcoxon signed-rank test compared compliance, confidence, adjustment, performance, and comfort scores between SR and WSR. For adjustment and confidence, a score of 100 was assigned if the participant did not report an adjustment or gain confidence within two weeks. The Kruskal-Wallis H test was used to determine any differences between SR, WSR and usual. Statistical significance was set to $p < 0.05$. All statistical analyses were performed in STATA (StataCorp, version 17). From the Standard Evaluation of Static Working postures from ISO 11226 [52], two categories were made for the lateral flexion neck angle: neutral (-10° to 10°) and awkward (>-10° or > 10°). The percentage of the working time spent in these two categories will be calculated and used for evaluating SR and WSR. Additionally, exploratory analyses were conducted, including amplitude probability distribution function (APDF) on the head angles to identify the static (P0.1), median (P0.5) and peak levels (P0.9).

2.6. Ethics

The Research & Innovation Organization approved the management of health and personal information in the study at the University of Southern Denmark (notification number 10.990). All participants gave written informed consent before their involvement in the study in accordance with the Declaration of Helsinki. Furthermore, we provided extended consent about the risk of participating in this study during the COVID-19 pandemic. The Regional Scientific Ethics Committee for the Regions of Southern Denmark assessed the study procedure and stated that further approval was not required (S-20202000-87).

3. Results

3.1. Participants' characteristics

Six violinists 21-55 years old were recruited: two amateurs, two professionals (a teacher and a freelancer) and two conservatory students (see Table 1).

Table 1
Baseline characteristics of all six participants, including trouble rating before and after the intervention. Before and after the intervention, trouble, defined as ache, pain and discomfort, was rated on an 11-point numerical rating scale (NRS), ranging from 0 (no trouble) to 10 (worst possible trouble). The mean (SD) is presented for continuous data, and for ordinal data, the median and nominal values are in numbers. Q1-Q3 refers to the interquartile range (IQR). The first quartile (Q1) is the upper boundary of the lower 25% of the dataset and the third quartile (Q3) is the lower boundary of the upper 25%

Screening characteristics of the study sample	Total	
Age (years) mean (SD)	33.2	(12.7)
Gender number (female/male)	3/3	
Level of playing (amateur, students, professional)	2/2/2	
Height (cm) mean (SD)	173.6	(6.3)
Weight (kg) mean (SD)	76.6	(10.1)
BMI (kg/m2) mean (SD)	25.3	(2.8)
Daily practice the last 12 months (hours) mean (SD)	3.2	(0.9)
Self-rated general health (numbers)		
Poor/less well	0	
Well	1	
Very well	4	
Excellent	1	
Age for starting with main instrument (years) mean (SD)	7.3	(1.8)
Different setups tried during the years (numbers) (Chin/ shoulder rest)		
1	0/0	
2-4	3/3	
5-9	2/2	
10 or more	1/1	
Trouble (ache, pain or discomfort) in the last 7 days		
Neck (NRS 0-10) (Q1-Q3)		
Baseline	0.5	(0-3.3)
Follow-up	2	(0.3-3)
Upper back (NRS 0-10) (Q1-Q3)		
Baseline	1	(0.3-1)
Follow-up	0.5	(0-1.8)
Right shoulder (NRS 0-10) (Q1-Q3)		
Baseline	0	(0-3.8)
Follow-up	1.5	(0.3-2.8)
Left shoulder (NRS 0-10) (Q1-Q3)		
Baseline	2.5	(1.3-5.3)
Follow-up	2	(0.5-2.8)

All six violinists participated in this study between August and October 2020.

All six violinists used a shoulder rest at the time of recruitment. Three violinists were content with their current chinrest, and five were content with their present shoulder rest. Four of six violinists had kept the chinrest attached to the violin when they bought it. The six violinists gave different motivations for participating in this project: 'being curious', 'finding a better chinrest', 'getting a better posture', and one wanted 'to learn to play without shoulder rest'.

Two professional violinists had the planned two-week familiarisation period extended (extra seven days) due to illness (interruption was 14 and 36 days). They played nine and ten days out of fourteen days before the interruption.

3.2. Adherence and compliance

Table 2 shows high adherence rates to daily play (median 89%, range 64-100%) over 14 days. Compliance differed significantly between using SR and WSR ($p = 0.04$). Median compliance for SR was 54.9%, and for WSR it was 45.1%, indicating less use of WSR. Two players played less than 25% with WSR and had low compliance rates (12.4% and 20.5%, respectively) out of the total playing time.

3.3. Usability

3.3.1. Confidence level, instruction comprehensibility and performance

For the violinists, it took a median of 6 days with WSR and 5 days with SR to reach a fair or

Table 2
Each violinist was given two weeks to play. Adherence (%) was estimated as the number of days played out of the 14 with the different setups. Total playing hours are given for the two weeks. Compliance was reached if the violinist managed to play at least 25% of the total playing time WSR (the EC played without shoulder rest) and at least 25% with SR (the EC played with a low shoulder rest). Q1-Q3 refers to the interquartile range (IQR). The first quartile (Q1) is the upper boundary of the lower 25% of the dataset and the third quartile (Q3) is the lower boundary of the upper 25%. *Indicate that WSR significantly differs with lower compliance than SR (P = 0.03)

Violinist	Adherence (%)	Total playing hours	Compliance (%)	
			WSR	SR
Amateur	64	13.3	45.3	54.7
Amateur	86	6.3	50.0	50.0
Student	100	25.7	20.5	79.5
Student	86	30.0	45.0	55.0
Professional	93	34.8	12.4	87.6
Professionel	100	19.5	45.4	54.6
Median (Q1-Q3)	89.3 (85.7-98.2)	22.6 (14.8-28.9)	45.1 (26.6-45.4)	54.9 (54.6-73.4)
Median difference			9.7* (9.2-59.1)	

very confident playing level. However, two violinists couldn't achieve confidence within two weeks with WSR, showing a significant difference in confidence-building time between WSR and SR ($P = 0.03$). All the video instructions were found effective for adjusting EC. Table 3 displays the playing performance score for both WSR and SR, with a significant improvement in performance for SR over WSR.

3.3.2. Adjustments

Adjusting WSR to work efficiently took a median of 6 days for five violinists, but one professional violinist did not find an adjustment in the 14 days. Adjusting to SR took a median of 1.5 days for all participants. No significant difference was found between SR and WSR in terms of efficiency.

3.3.3. Comfort

Table 3 displays the comfort score for both WSR and SR, with no difference found in comfort scores between the two conditions.

3.3.4. Sound

We found no difference between the overall sound or tone between WSR and SR. Three participants answered 'very good' or 'good' for tone and overall sound when playing WSR and SR. Only one participant scored 'bad' for tone and overall sound for both conditions.

3.3.5. Emotions

The six participants recorded different comments in their diaries on an average of 8 out of 14 days (ranging from 3-13 days). The median number of comments made was 4 (ranging from 0-8), with most comments being negative (26 out of 33). The median number of comments about WSR was 5.5 (ranging from 2-8), about SR was 2.5 (ranging from 0-5), and in general was 4 (ranging from 2-5). The negative comments were about "*causing pain/tension*", "*being uncomfortable*", "*not being able to play difficult things with quality*", and "*difficult or impossible doing shifting position and making more playing mistakes*". The positive comments were mainly that it improved to be less painful and easier to play using WSR during the two-week familiarisation.

There were mainly positive comments for SR (12 out of 15), including additional comments such as '*it worked with the setup*' and '*it was quite comfortable*'.

General comments were both negative and positive. The negative ones were mainly about difficulties regarding adjustment and time spent adjusting EC. Another negative comment was that the violin case cannot be closed without removing EC from the violin because of its height. The positive comments contained feedback on a better sound from EC, the experience of less tension while playing, and the fact that they were happy to participate in the study.

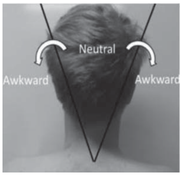
3.4. Secondary outcome

The percentage of playing time spent in an awkward lateral neck posture (to the left or right, at an angle greater than 10°) was calculated. Three out of six violinists spent over 20% of their playing time (ranging from 23% to 74.5%) in an awkward posture with their usual condition, while the rest spent less than 10% (ranging from 2% to 7%). For three violinists, the awkward neck posture increased with either WSR or SR but decreased for the other three (see Table 4). Overall, both SR and WSR resulted in less time spent in the awkward posture than with their usual condition.

Table 3
Performance and comfort scores are presented as the median (Q1-Q3) for WSR (the EC played without shoulder rest) and SR (the EC played with a low shoulder rest). Q1-Q3 refers to the interquartile range (IQR). The first quartile (Q1) is the upper boundary of the lower 25% of the dataset and the third quartile (Q3) is the lower boundary of the upper 25%. A higher score (range 0-100) indicates a negative or reduction in playing performance or comfort. *Indicates a significant difference at $p < 0.03$ with the Wilcoxon signed-rank test

	WSR		SR		Median difference	
	Median	Q1-Q3	Median	Q1-Q3	Median	Q1-Q3
Performance score	58.3	41.7-66.7	4.2	0-25	45.8	33.3-58.3*
Comfort score	40	25-50	30	10-50	10	0-10

Table 4
The lateral neck posture angle is categorised into two groups: neutral (-10° to 10°) and awkward (>-10° or > 10°) based on the ISO 11226 Standard Evaluation of Static Working postures. WSR refers to playing with the ergonomic chinrest (EC) without a shoulder rest, while SR refers to playing with the EC and a shoulder rest. The table shows the percentage of time spent in an awkward neck posture position out of the total playing time for each condition. Q1-Q3 refers to the interquartile range (IQR). The first quartile (Q1) is the upper boundary of the lower 25% of the dataset and the third quartile (Q3) is the lower boundary of the upper 25%



	Time spent in awkward position (%)			Median difference		
Participants	Usual	WSR	SR	Usual- WSR	WSR-SR	Usual-SR
Amateur	74.5	6	5			
Amateur	7	11	0			
Student	3	4	9			
Student	23	17	9			
Professional	2	43	12			
Professional	29	2	8			
Median (Q1-Q3)	15 (3-29)	8.5 (4-17)	8.5 (5-9)	2.5 (-4-27)	4.5 (-5-11)	2.5 (-4-27)

For all conditions, the neck angle was at the P0.1 level under 4°, the P0.5 level around 4-5° and the P0.9 level around 10°. Meaning that 90% of the time, the violinist's neck position was under 4° and around 10° for 10% of the time (see Fig. 3). However, the Kruskal-Wallis shows no significant difference comparing the medians between the three conditions.

4. Discussion

4.1. Summary of findings

This study evaluated the feasibility of a novel EC used by violinists in combination with SR and WSR over a two-week familiarisation period. The feasibility study found that familiarisation with SR was positive and successful, with high compliance and usability. However, WSR was not feasible due to two violinists not meeting the minimum playing time criterion and lower usability outcomes than SR, including two violinists failing to reach a confidence level, multiple challenges noted in diaries, and lower performance. On the other hand, the participants displayed high adherence to playing with EC (89%), no sound changes were detected, all instruction videos were rated sufficient, and the participants expressed gratitude for participating in the study.

4.2. Feasibility of EC

This study is the first to investigate the feasibility of using an EC with SR and WSR from the perspective of violinists' data collection on usability (effectiveness, efficiency, and satisfaction). Considering violinists' subjective evaluations when implementing or testing an EC is important. Prior to testing the biomechanical features of playing with the usual chinrest and shoulder rest or the EC in combination with SR or WSR, we evaluated the feasibility of different conditions. This gained important insights and informed us about potential barriers and possibilities, allowing us to plan the larger study trial.

In the violin society, the debate about ergonomic equipment mainly focuses on shoulder rests. This might be because a violin is typically purchased with a chinrest installed, while a shoulder rest is bought supplementally. This is also reflected in this study, where four out of six participants kept the chinrest that came with their violin when they purchased it. Another debate is whether to use shoulder rest. Players favouring a shoulder rest argue that it facilitates

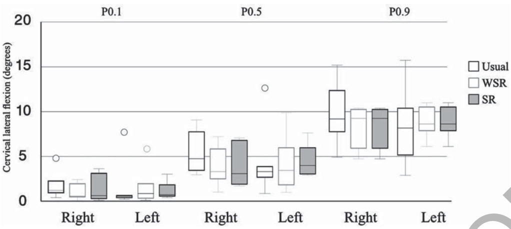


Fig. 3. Cervical lateral flexion angle (°) is presented as the median (IQR) over the different levels in the amplitude probability distribution function (APDF). WSR: without shoulder rest and SR: shoulder rest.

better control and use of playing technique with less muscle tension. Those against it argue that it makes the left arm more inactive and static and dampens the sound. In this study, no overall tone or sound change was perceived between WSR and SR.

Scientific studies have explored the use of shoulder rests, with varying results on the best way to adjust or use them [29, 31, 34]. Kok et al. discovered that playing with the highest or without a shoulder rest was the least comfortable compared to playing with a lower shoulder [34]. Rabuffetti et al. found that using a high shoulder rest reduces neck rotation and allows violinists to adapt to different playing conditions without affecting the sound, similar to the results found in our study [31]. Additionally, using a Kun shoulder rest resulted in lower muscle activity in the upper trapezius and neck muscles compared to not using it [29]. One study investigated three different chinrests in combination with two shoulder rests and found that all chinrests change the pressure and chin force and that the shoulder rests change the pressure and contact area utilised over the chinrest [30]. None of the studies considers that the results may differ if the musicians have had a familiarisation period playing with the new equipment. Furthermore, they do not include the importance of a subjective approach where violinists can try and adjust the equipment to their anthropometric body features.

All the participants recruited for this project played with a shoulder rest before the study began, which may have influenced the results. However, in Denmark, the standard is to play with a shoulder rest when you learn to play the violin. This study found a significant difference in performance scores between the two conditions and decreased comfort scores when using a WSR. Playing technique and shifting problems described in the diary may be one of the reasons for the low-performance score and a barrier to playing using WSR. One study found that low or no shoulder rest biomechanically was the best condition, supporting the findings in our study that low shoulder rest was evaluated as the most comfortable [34].

Two major limitations of this feasibility study are the small sample size of six violinists with different backgrounds, which limits the generalizability of the results. Due to the COVID-19 pandemic and national restrictions, it was impossible to recruit the planned number of participants. However, previous research supports our findings, suggesting that a low shoulder rest should be evaluated based on the low comfort reported WSR [34]. The feasibility study results consistently point in the same direction, indicating that playing playing the violin WSR is less feasible and more problematic for the investigated study group, this is supported by negative feedback comments and low compliance. Despite the limited number of participants in this study, the data collected was not only exploratory but due to the indicated consistency also found valuable for the design and the content of a following larger-scale study evaluating whether neck muscle activity can be lowered using the EC with SR and how it affects the neck position [53]. The feasibility study can only be taken as "direction pointing", but its main strength lies in its testing of multiple intervention elements with consistent results. The second limitation is that this study used self-developed usability outcomes, which lacks the established standardisation found in widely used scales such as the System Usability Scale [54]. This is a limitation as the results cannot be compared to those obtained using validated standardised scales and can raise concerns about the measurements' accuracy, consistency, and comparability. However, it is important to note that usability is context-dependent, and this study represents an initial step and insight in exploring usability within this specific context, laying the foundation for future research in this area.

5. Conclusion and perspectives

This small study presents the feasibility of a familiarisation period using EC for violinists. Playing the violin with SR shows high compliance and usability. In contrast, the findings indicate low feasibility WSR, and two out of six violinists did not meet the criteria of minimum playing time. Playing WSR with EC is a challenge for violinists who usually play with a shoulder rest: low-performance score and a longer time to get confident than SR. A larger study trial is conducted to evaluate whether the EC with SR can lower the muscle activity in the neck muscles and change the lateral neck position compared to a preferred chinrest. Although the study had a limited number of participants, it may interest others in the field due to the valuable data produced by its methods and results, as research in this area is limited. This study protocol can be used as inspiration for incorporating different usability outcomes (sound, playing performance/comfort and user feedback) when investigating musicians going through an ergonomic intervention.

Ethical approval

The Regional Scientific Ethics Committee for the Regions of Southern Denmark assessed the study procedure and stated that approval was not required (Date: 2020, Number: S-20202000-87).

Informed consent

All participants provided written informed consent prior to their participation in the study.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The Kréddle company was not involved in the design of the study, the execution, analyses, data interpretation or decision about submitting the results.

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Appendix: Template for Intervention Description and Replication (TiDieR) Items 1-12

Item 1: Brief name	Unsupervised adjustment with an ergonomic chinrest (Kréddle) used with and without shoulder rest (Kun) for two weeks
Item 2: Why	The aim is to test the feasibility of an ergonomic chinrest with and without a shoulder rest for two weeks. Secondary to evaluate neck alignment compared to using their usual chin- and shoulder rest.
Item 3: What (materials)	• The Kréddle chinrest and Kun shoulder rest • Two-week paper diary • Information videos on YouTube • Information letter about the project and the focus of aligning neck position.
Item 4: What (procedures)	Unsupervised adjustment of the Kréddle and Kun shoulder rest during a two-week period before the test in the laboratory • An online questionnaire is given before a two-week familiarisation period. A two-week diary was filled out every day, and in the end, an online questionnaire was given before the test in the laboratory. • Before adjusting the Kréddle, the violinists watched three YouTube videos about the project. • After seven days a motivational phone call was given from the principal investigator to keep the violinist motivated to fill in the diary and play with the Kréddle.
Item 5: Who provided:	The principal investigator provided the violinists with all the material and the YouTube videos
Item 6: How	Information was sent by mail. The two-week diary including the ergonomic chinrest (Kréddle) and shoulder rest (Kun) was sent by post or delivered to the violinist's workplace.
Item 7: Where	The unsupervised two-week familiarisation period was carried out at the violinist's workplace or at home.
Item 8: When and how much	The violinists should play all their playing time with the ergonomic chinrest (Kréddle) and shoulder rest (Kun). If deviating from this the violinist should write hours played with their usual setting in the diary and explain why.
Item 9: Tailoring	During the two-week familiarisation period the violinist can adjust and play with the ergonomic chinrest in many different positions each day until they find an adjustment that suits them.
Item 10: Modifications	The violinists were allowed to change the height of the Kun shoulder rest if the highest post from Kréddle was not tall enough or to adjust the Kun if the violin was smaller than the usual standard measurements.
Item 11: How well (planned)	The principal investigator encouraged each violinist to the two-week period and the rationale of an aligned neck position was made clear. Before including the violinists into the project each violinist had a personal phone call with the investigator explaining about the project and rationale. After inclusion the violinists could contact the investigator with any questions at any time. YouTube videos and information letters were handed out explaining how to adjust and use the ergonomic chinrest.
Item 12: How well (actual)	This study investigated how well the protocol worked for an unsupervised adjustment of the ergonomic chinrest (Kréddle) and shoulder rest (Kun) by looking at the adherence and compliance to the two-week familiarisation period and was described in this article.

Paper III

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The effects of an ergonomic chinrest among professional violin players. A biomechanical investigation in a randomised crossover design

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ABSTRACT

This study aimed to compare violinists' upper body kinematics and muscle activity while playing with different supportive equipment: their usual chinrest (UC) or an ergonomic chinrest (EC), each mounted on the violin. Three-dimensional motion capture and electromyographic data were acquired from the upper body while 38 pain-free professional violinists performed an excerpt of a music piece. There were only minor differences between the two set-ups tested. The EC resulted in less left rotation of the head (3.3°), slightly more neck extension (1.3°) and less muscle activity (0.5–1.0 %MVE). However, the overall high static muscle activity (4–10 %MVE across all muscles) was maintained using EC. For both setups, the head posture was left-rotated >15°, ≤6° flexed and left-bent 90% of the time. The EC did not produce a substantial difference in biomechanical load. Instead, future studies may focus on aspects other than chinrest design to lower the static workload demands.

1. Introduction

The violin has been a popular instrument since it was developed approximately 500 years ago by the violin builder Andrea Amati (Ranelli et al., 2011). It may be hard for the listener to imagine that an instrument with such a beautiful sound often evokes discomfort and pain. However, musicians as an occupational group experience a higher prevalence of upper body pain than other occupations (Paarup et al., 2011). Violin playing is especially problematic compared to other instruments (Nyman et al., 2007; Rensing et al., 2018). The violin is placed between the jaw and the left shoulder, with the left arm and head in a prolonged awkward static position and pressing down on the instrument. The right arm moves the bow across the strings repetitively, while the right shoulder maintains a static load to hold the bow above the instrument. Forward or sideways neck flexion, repetitive movements, and static loading are well-known risk factors for developing shoulder or neck disorders (Larsson et al., 2007). Not surprisingly, violinists' most affected body regions are the left side of the upper body, neck, and shoulders, including the temporomandibular joint (Kochem and Silva, 2018; Mizrahi, 2020; Moraes and Antunes, 2012).

Violinists seek an optimal violin positioning for multiple reasons: To 1) stabilise the violin held between the jaw and left shoulder; 2) reduce musculoskeletal load/tension and discomfort; and 3) give more freedom of movement to the left hand (Araújo et al., 2021; Obata and Kinoshita, 2012). Therefore, many violinists experiment with ergonomic equipment, such as alternative chin and shoulder rest designs, today. For example, an adjustable shoulder rest, available in different designs to accommodate different body types and shoulders, is attached to the bottom of the instrument (Thomann, 1954). In contrast, the chinrest attached to the violin's surface typically has limited adjustments, such as height or placement on the instrument, unless it is customised by a violin builder to accommodate the player's neck length or playing style. Since these two devices were invented, there has been much practical trial and error and discussion about how to use them to achieve an aligned working posture with less tension (Norris, 1993). Scientific evidence about how best to adjust either one remains scarce, and the methodological quality of the available studies is inconsistent (Chi et al., 2020).

Prior studies mainly focused on biomechanical evaluations of shoulder rest designs (Kok et al., 2019; Levy et al., 1992; Rabuffetti et al., 2007; Wong and Lei, 2016). Kok et al. found that a low shoulder rest was biomechanically the best and the most comfortable among 20 violinists. However, they suggested that a higher chinrest may result in lower muscle activity in the left arm and decreased left rotation and lateral flexion of the head (Kok et al., 2019). These prior studies did not

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include either a familiarisation period or adjustments to the individual players' anthropometrics (Chi et al., 2020). Likewise, no previous study has investigated the biomechanical changes when violinists use their usual setup compared with an attempt to improve ergonomics.

In 2020, we searched for ergonomic violin equipment and found only one adjustable ergonomic chinrest (EC), which can be adjusted in six dimensions and locked in a specific position of the player's choice (Hayes, 2013). This chinrest can be customised in height and can be tilted and rotated to fit the player's arm and neck length and playing style. Keeping the neck more aligned without pressing the jaw down into the chinrest may lessen the muscle activity around the neck and shoulders.

This product differs from other ergonomic chinrests on the market, which only have a few adjustments unless customised. The height of the shoulder rest is often prioritised over the adjustment of the chinrest, and this is also reflected in the scientific literature, which has primarily focused on shoulder rests (Kok et al., 2019; Levy et al., 1992; Rabuffetti et al., 2007; Wong and Lei, 2016).

Based on a previous study that showed a low shoulder rest to be the most comfortable (Kok et al., 2019), we conducted a feasibility study to test this particular EC when used with either a low shoulder rest or none. The prior feasibility study showed high compliance and acceptance of using an ergonomic chinrest (EC) after a familiarisation period and that playing with a low shoulder rest was more feasible (higher performance, comfort and positive feedback) than playing without a shoulder rest (Mann, 2022). Based on those findings, the present study was designed to compare upper body kinematics and muscle activation patterns during violin playing between an usual chin and shoulder rest (UC) and an ergonomic adjustable chinrest and low shoulder rest (EC).

The hypotheses were that playing with EC, compared to UC, would lead to 1) less lateral tilting of the head to the left and less forward neck flexion; and 2) lower static muscle activation in the right sternocleidomastoid, neck muscles, left upper trapezius and deltoid muscles.

2. Methods

2.1. Study design

We designed a crossover, block-randomised (block sizes of 4) and within-subjects experimental design. Both the UC and EC conditions were tested in a randomised order in one 3-h-long session, including a 5-min wash-out period to prevent a carryover effect between each condition (Wellek and Blettner, 2012). The 5-min wash-out period was based on a former study which concluded that professional violinists could quickly adapt to different shoulder rests without affecting sound quality (Rabuffetti et al., 2007). An instruction video explained how to adjust the EC, by keeping the head aligned without left lateral head flexion and flexed head (Mann, 2020a, 2020b). All participants had a mandatory familiarisation period of 2 weeks with the EC before the test day. If a violinist became ill or was interrupted in playing with EC for more than five consecutive days during the familiarisation period, the period was extended by two extra days.

The following week, the designed crossover test was conducted, following a protocol that was shown to be feasible (Mann, 2022) This trial was retrospectively registered at ClinicalTrials.gov. (NCT05604313) and is reported in accordance with the Consolidated Standards of Reporting Trials (CONSORT) 2010 extension to randomised crossover trials (Dwan et al., 2019). Enrollment was conducted in January 2021 and discontinued from late January 2021 to the beginning of June 2021 due to the COVID-19 pandemic. A new enrollment period was initiated and ended in January 2022.

2.2. Participants

Participants were recruited from professional symphony orchestras in Denmark, a Danish Conservatory, via social media and by word of mouth. Participants were eligible if they were 18 years or older, could speak and write Danish or English fluently, and had graduated from a music conservatory with violin as the main instrument or enrolled at the master's degree or soloist class at the conservatory. Volunteers were included if they also reported no severe pain symptoms in the neck or upper extremities ≤ three scored on a numeric rating scale from 0 (no pain) to 10 (worst perceived pain) at the time of recruitment. The exclusion criteria were.

1. Medical conditions that could influence test results (pacemaker or life-threatening health disorders),
2. Trauma on the upper cervical spine or upper extremities within the last 12 months,
3. Previous or planned shoulder/neck surgery, and
4. Severe eczema on the neck or upper extremities.

All participants provided written consent before enrolling in this study, including extended consent about the risk of participating during the COVID-19 pandemic. Assessment of the study procedure was evaluated by the Regional Scientific Ethics Committee for the Regions of Southern Denmark, and no approval was required (S-20202000-87).

2.3. Description of the usual and ergonomic chinrest/shoulder rest

We collected information about the height of UC and EC to evaluate the different adjustments of the chinrest and shoulder rest. In the

Table 1
Descriptive demographics and baseline characteristics for groups 1, 2 (the randomised playing order) and the whole group. Adherence was counted as the number of days playing with the EC out of the two weeks. Compliance for playing with EC was hours played out of total playing time.

Screening characteristics of the study sample	Group 1 UC- EC (N = 19)		Group 2 EC-UC (N = 19)		Total (N = 38)	
Age (years) mean (SD)	41.8	(12.8)	43.5	(11.5)	42.6	(12.0)
Gender number (female/male)	15/4		11/8		26/12	
Level of playing (students, professional)	3/16		0/19		3/35	
Height (cm) mean (SD)	170.8	(11.3)	170.7	(8.5)	170.8	(9.9)
Weight (kg) mean (SD)	70.7	(17.5)	77.1	(12.9)	73.9	(15.5)
BMI (kg/m2) mean (SD)	24.2	(5.6)	26.5	(4.0)	25.3	(4.9)
Daily practice the last 12 months (hours) median (IQR)	4.5	(2)	4.5	(1.5)	4.5	(1.5)
Current work ability (0 = unable to work, 10 = best work ability), median (IQR)	9	(2)	8	(1)	9	(2)
Age for starting with main instrument (years),median (IQR)	7	(3)	7	(3)	7	(3)
Playing years with main instrument, median (IQR)	34	(21)	38	(15)	36	(17)
Different setups tried during the years (numbers) (Chin/shoulder rest)						
1	0/1		2/1		2/2	
2–4	10/11		8/7		18/18	
5–9	6/7		4/6		10/13	
10 or more	3/0		5/5		8/5	
Familiarisation period (two weeks)						
Total days played out of 14 days, median (IQR)	12	(3)	12	(4)	12	(4)
Total hours played during the 14 days, median (IQR)	39.3	(18.8)	32.5	(17)	37.8	(17)
Adherence (%), median (IQR)	85.7	(28.6)	85.7	(21.4)	85.7	(28.6)
Compliance (%), median (IQR)	99.4	(11.8)	100	(17.0)	99.7	(16.6)

method section, Table 2 shows 1) the total height measured from the top of the table where the violin was placed to the highest point of the chinrest and 2) the height from the table to the bottom of the violin (shoulder rest height measurement). The EC (Kréddle®, Wyoming, US) has different components for individual personalised adjustment. Information about the participant's preferences was collected. During the familiarisation period, the participants chose between 1) two different chin plates (one thinner, one thicker) to accommodate different jaw shapes and 2) four different post heights adjusted to the neck length. The chinrest was attached to the violin on a base next to the string holder. The EC was used with a Kun Super shoulder rest set in the lowest position on both sides (Fig. 1).

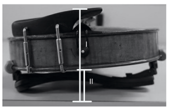
2.4. Questionnaires and measurement procedures

Participants completed a baseline web-based questionnaire before the familiarisation period, including demographic characteristics, previous experience with ergonomic equipment and pain in the upper body rated on a Likert scale from 0 (no pain) to 10 (worst possible perceived pain) (Kuorinka et al., 1987). A follow-up questionnaire was given right after the familiarisation period, including follow-up questions on pain in the upper body, hours played during the last seven days and evaluation of the time to familiarise with the novel EC.

The participants had access to music scores and warm-up protocol two weeks before the test day (Appendix A[1-2] shows the different scores). They were instructed to practice the protocol with a metronome set to crotchet = 60 beats per minute using specified techniques to be familiar with the scores. Daily playing hours were registered in a diary during the two weeks familiarisation period. Adherence was evaluated as the number of days playing with the EC and compliance as hours played with the EC of total playing time. Participants were told not to perform high-load resistance training or heavy work within two days before the test, to avoid muscle fatigue or soreness.

On the test day, the participants were asked to hold a static playing posture for 20 s: the middle of the bow resting on the D-string (a violin has four strings: G, D, A, E) and the left hand holding the violin neck in the first position. Immediately after, they had a standardised warm-up protocol, including playing two different scales at four different speed levels (A and E major) and an A major scale at slow speed with vibrato. The warm-up playing protocol was followed by an excerpt of a music piece (second movement from W. A. Mozart's violin concerto no. 5 in A major), which was played in a loop of 4 repetitions without a break (76s x 4). This procedure was performed with both the UC and EC while in a seated position (Fig. 1).

Table 2
Describes the adjustment of height for UC and EC. The total height adjustment measured from the top of the table to the highest point of the chinrest (I) and the height of the shoulder rest from the top of the table to the bottom of the violin (II).



	Height adjustment in total (cm)	Height adjustment of the shoulder rest (cm)
	Median (CI)	Median (CI)
UC	11.3 (10.9–11.9)	5.2 (4.8-5-5)
EC	12.6 (12.2–12.8)	4.5 (4.4–4.6)

2.5. Cameras (setup, calibration, and processing)

Eight infrared Vicon T20 (2 megapixels) cameras and one Bonita digital high-speed camera (1 megapixel) were placed 1–2 m from the participant sitting in a 36 m^2 room. The cameras were driven by Nexus software (version 2.12) at a sampling rate of 200 Hz (Vicon Motion Systems Ltd., Oxford, UK) and connected to a computer with the software for data acquisition and processing.

Reflective surface markers of 14 mm were used and placed over anatomical landmarks on the head (n = 4), neck (n = 1), trunk (n = 2), shoulders (n = 2), shoulder blade (n = 1), arms (n = 6) and hips (n = 2) (Appendix B displays the placements of the kinematic markers and EMG electrodes).

We followed the International Society of Biomechanics recommendation for marker placement (Wu et al., 2005) and a neck model designed for the posture of the neck/head and upper body (Brink et al., 2013; Straker et al., 2008). A 10-s sitting aligned posture was held to locate joint centers and rotation axes and create a personalised kinematic model. Joint angles were performed in ProCalc from Vicon (version 1.5.0), including angles as follows: 1) head flexion, 2) head lateral tilting, 3) head rotation, 4) trunk flexion, 5) trunk rotation and 6) arm abduction. (Appendix C shows the joint angle calculations).

The chosen kinematic model has been used in previous work to measure head and upper body kinematics and to construct the segments and estimates of the joint centers (Brink et al., 2013; Hesby, 2019; Straker et al., 2008). Furthermore, two categories were constructed for the lateral head tilting as neutral (<10°) and awkward (>10°) made on the Standard Evaluation of Static Working postures from ISO 11226 (ISO, 2000). The percentage of the working time spent in the awkward position will be calculated and used for evaluating UC and EC.

The principal investigator processed data after the markers' reconstruction and labelling. The raw data were filtered using a Woltring filter with a mean square error of 10 to reduce and minimise the marker trajectory noise. If a marker was missing and could not be reconstructed, that time point was removed and not analysed.

2.6. Electromyography

Wireless sEMG (Myon 320, AG, Switzerland) was used, and electrodes were placed to measure muscle activity bilaterally from the upper trapezius muscles (UT), upper neck extensor muscles (NE), sternocleidomastoid muscles (SCM) and on the right medial and left anterior deltoid muscle (DT). Before placement of the electrodes, the skin was shaved, scrubbed, and cleaned with 70% alcohol to secure an interelectrode impedance <20 kΩ. Bipolar electrodes (Ambu Blue Sensor, N-00-S/25, Denmark, Ag/AgC1) with a gel measuring area of 95 mm^2 were placed with an interelectrode distance of 20 mm parallel to the muscle fibers. The raw sEMG signals were analogue bandpass filtered from 5 Hz to 500 Hz (4th order). The amplified sEMG signals were sampled at a sampling rate of 2000 Hz with a 16-bit A/D converter (NI-USB 6210, National Instruments Corporation, USA) and stored using custom build recording software. Custom-made software (Hedera 4.0, University of Southern Denmark) was used for further analyses.

During six maximal voluntary isometric electrical contractions (MVIC), the highest EMG value was detected for UT, NE, SCM and DT and was used for normalisation. Each MVIC included three trials, with each contraction lasting 5 s and a 1-min break. The order of the six MVICs was randomised, with a 1-min break between and including a standardised warm-up (Essendrop et al., 2001; Faber et al., 2006; Schwartz et al., 2017) (Appendix D). After each MVIC, participants were asked on a scale from 0 (nothing performed) to 10 (performed maximally) if performance was maximal. A retrial was performed if they scored below eight to secure maximal performance. The digital signal of the EMG amplitude was represented as the root mean square (RMS) in a window size of 1 s. During the MVIC, a window size of 1 s moving in 100 ms steps was used to detect the highest RMS. For the playing task

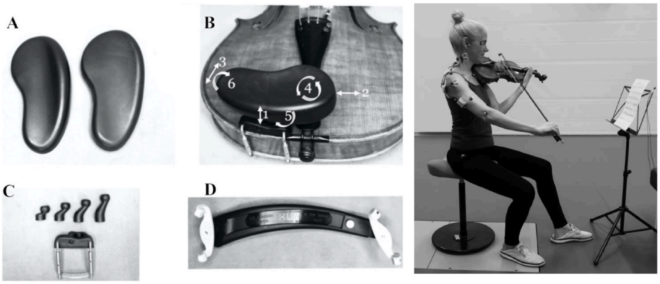


Fig. 1. The left picture shows the different parts/adjustments of EC (A–C) and the Kun Super shoulder rest (D). A) The chin plates: two different shapes (thicknesses), B) different adjustments: 1) height, 2) lateral movement, 3) backwards-forward, 4) rotation, 5) pitch angle and 6) tilt angle, C) the four different posts for adjustments of the height including the base attached to the violin and D) the Super Kun shoulder rest with both sides (legs) adjusted to the lowest position. The picture on the right shows a violinist playing a music piece while kinematics and muscle activity is being measured.

(repeated music piece), the event was set for the entire period and analysed in 1 s epochs.

2.7. Sample size

The required sample size was estimated based on data on head position (being in an awkward or neutral position) from the previous feasibility study (Mann, 2022) and planning for a two-sided, paired-sample McNemar test. The study required a sample size of 34 pairs to achieve a power of 80% and a statistical significance of 5% for detecting a difference of −0.25 between marginal proportions. Additional participants were recruited in case there were data losses or dropouts.

2.8. Statistical analysis

All data were analysed with STATA version 17.0 software. Descriptive data are presented as the means (SD) or medians (IQR) depending on the data distribution for each variable. A probability level of ≤ 0.05 was defined as statistically significant. We used a linear mixed-effects model with the treatment (UC and EC) and the period effect (Period 1: UC or EC; Period 2: EC or UC) as fixed variables and subjects as the random component affecting the primary outcomes of muscle activity and kinematics (Wellek and Blettner, 2012). The residuals were checked for normality using QQ plots for this linear mixed model. The regressions were performed following the latest CONSORT statement for randomised crossover trials assuming the absence of a carry-over effect (5 min were considered enough as a wash-out period) (Wellek and Blettner, 2012). A Wilcoxon signed rank test was performed for the variable of time spent in awkward playing posture $>10^{\circ}$ due to a skewed data distribution.

The amplitude probability distribution function (APDF) was computed for all muscles and head angles to identify the static (P0.1), median (P0.5) and peak levels (P0.9). An exposure variation analysis (EVA) was conducted to explore the underlying variation in muscle activity over time in the two setups and only for one specific muscle with the most significant muscle activity change. The EVA comprises a matrix with the percentage of cumulative time (%), amplitude level (EMGmax) and length of time at each amplitude level (seconds).

3. Results

3.1. Participants

In total, 62 professional violinists accepted to participate in this study, of whom 38 were finally enrolled and analysed (Fig. 2).

The participants were mostly female and mostly professionals rather than students, with over 30 years of violin experience (Table 1). Two participants usually played standing, 21 played seated, and 15 varied between sitting and standing. All enrolled participants used a chinrest before the study; 36 always used a regular shoulder rest, of whom one preferred a thick foam shoulder rest and one changed between a regular shoulder rest and foam. Of these two, only one performed the playing procedure on the test day with the thick foam shoulder rest (not soft), which was comparable to the height of a regular shoulder rest. Of the 38 participants, 21 rated their health as very good or excellent, 16 as well, and one as less well/poor. Before the familiarisation period began and during the last seven days of the familiarisation period, all participants had a score <2 for trouble (ache, pain or discomfort) in the upper body.

Ten participants had two days' extension of the familiarisation period due to an interruption related to the COVID-19 pandemic. Additionally, one was excluded from the MVIC test for medical reasons; one had an upper body pain score >3 during the test day but performed the MVICs; two were tested during early pregnancy which was not detected until after their inclusion.

3.2. Adjustments of chin and shoulder rest

Table 2 shows that the total height in cm was significantly higher with EC (median 12.6 cm) than with UC (median 11.3 cm). There was no difference in shoulder rest height for playing with UC or EC. No difference was found between group 1 and 2 with the adjustment (Appendix E).

Of the four different heights for EC, most chose the two lowest post heights (71%) and the thick chin plate top (60.5%). The violinists had to self-adjust the EC without changing the shoulder rest height, but a few adjusted the shoulder rest slightly:

1) Four violinists played with another shoulder rest because their violins were smaller than a standard violin. However, the used shoulder rests (Kun original, Wolf and Everest) were adjusted to the same height and had a shape close to the Kun Super shoulder rest; 2) One violinist played with the Kun Super shoulder rest for both setups (UC and EC)

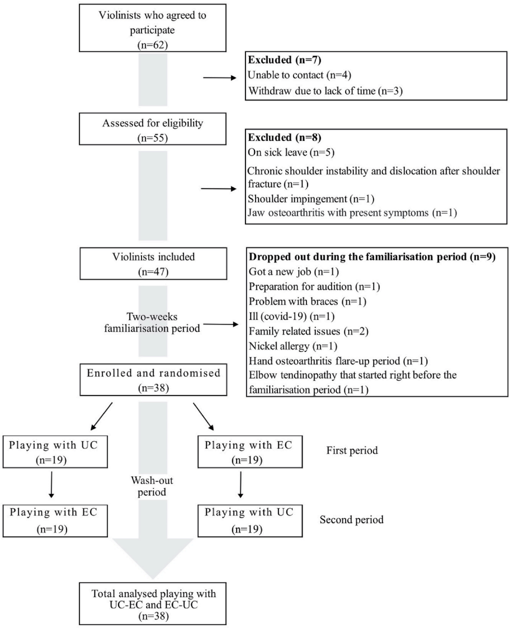


Fig. 2. Flow diagram including the crossover design during one test day.

because the usual shoulder rest broke; 3) One violinist adjusted the shoulder rest to be slightly higher (0.5 cm) above the sternum because of pressure pain on clavicula; and 4) One violinist did not follow the familiarisation protocol but played using the EC with the usual shoulder rest and without adjusting it to the lowest position; however, on the test day, this participant used the Kun shoulder rest in the lowest position.

3.3. Playing kinematics (mean level)

Kinematic analyses of the playing periods 1 and 2 are presented in Fig. 3, with mean values including the overall mean. No differences were found between UC and EC in degrees, with periods 1 and 2 as fixed variables for trunk flexion-extension, trunk rotation, left and right upper arm and head lateral tilting. EC showed significantly more head extension of 1.3° and less left head rotation of 3.3° than when playing with UC. Overall, the mean level for both UC and EC was <10° in head extension and above 20° for left head rotation.

The violinists were positioned with trunks extended (approximately 2°) and left rotated (approximately 1°) independently of which setup (UC vs EC). The left arm was lifted at approximately 40° and the right at approximately 60°. In this playing position, the mean value for lateral tilting of the head was between 1° and 2°.

3.4. Playing kinematics (APDF)

The APDF showed minimal differences in head extension/flexion and rotation at all levels (P0.1, P.05 and P0.9) (Fig. 4), with EC showing significantly more head extension and less left rotation. UC and EC differed by −1.4° and −1.0° in head extension at P0.1 and P0.9, respectively. For left head rotation, the difference between UC and EC was 2.5° and 3.8° at P0.1 and P0.9, respectively.

On average, the violinists maintained a lateral head tilt of 6° or more to the left during 90% of their playing time, which did not differ between UC and EC. Instead, the violinists demonstrated a lateral head tilt of 6° or more to the right for 10% of the time. The percentage of time spent with a lateral head tilt greater than 10° was also similar between UC (median 10.0%, IQR 27.3%) and EC (median 11.0%, IQR 26.1%). Half of the participants (N = 19) showed an increase in the time spent in the lateral head tilt position (median difference = −4.1%, IQR = 9.5%), while the other half (N = 19) showed a decrease (median difference = 6%, IQR = 8.6%)

3.5. Muscle activity when playing (mean levels)

Independent of the two setups, the muscle activity in both periods for

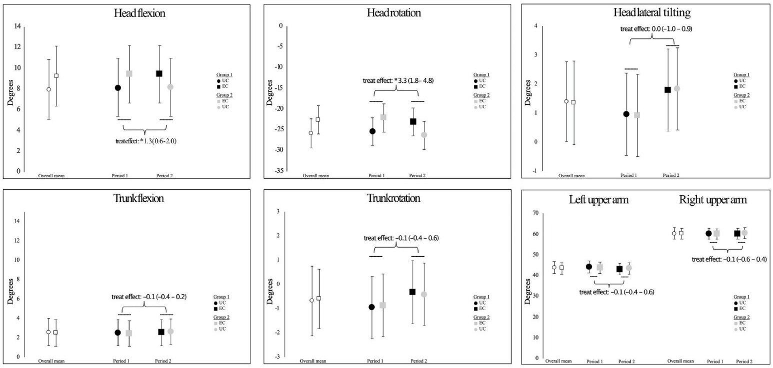


Fig. 3. Average kinematic angles (°) with 95% CI for head and upper body posture. This figure displays the overall mean and the first test period (Period 1) and the second test period (Period 2), including group 1 (randomised playing order: UC-EC) and group 2 (randomised playing order EC-UC). The treatment effect (treat) is the difference in degrees between UC and EC.*denotes a significant difference <0.05 in p-value between UC and EC with periods one and two as fixed variables.

both UT, NE, and left DT was >10 %MVE, and for right SCM, it was approximately 10 %MVE (Fig. 5). For the left SCM and right DT, it was approximately 6% MVE or less. Minimal muscle activity differences were found for UT, NE and SCM (<1 %MVE). No differences were found for the right medial DT or left anterior DT. For all muscles except DT, the muscle activity was lower in the static posture (20s hold) than actively playing a music piece (Appendix F).

3.6. Muscle activity when playing (APDF)

The static level of muscle activity was below 10% MVE for 90% of the playing time, regardless of the setups (Fig. 6). This level remained almost unchanged at the median level, around 10% MVE, and increased slightly to around 14% MVE at the peak level. The activity of the left SCM remained almost unchanged across the different levels, ranging around 4–6 %MVE. For all levels, minimal differences were found for UT, NE, and the right SCM (below 1 %MVE for using EC).

3.7. Muscle activity when playing (EVA)

EVA analysis of the right SCM (Fig. 7) showed no clear difference between UC and EC overall. The EVA was associated with a muscle activity pattern ranging from short to extended durations in both setups. The most prominent difference was seen for durations (>3–7 and >7–15) with activity levels from 10 to 20 %MVE for UC compared to 5–10 %MVE for EC.

4. Discussion

This experimental study examined the efficacy of a violin chinrest designed to reduce non-neutral head postures by permitting higher total height adjustment (i.e., a higher chinrest). The EC produced disappointingly small effects on neck kinematics and muscle activity. Using EC showed less head left rotation (3.3°), more extension (1.3°) and less muscle activity (≤0.5 %MVE for UT, NE and 1 %MVE for right SCM) compared to UC.

There was no change in lateral tilting of the head using the EC. The violinist's head was positioned 6° left in 90% of the playing time and 6° to the right 10% of the time. Only 10% of the total playing time was spent with >10° lateral head tilting, regardless of which chinrest was used.

The right and left SCM showed reductions in muscle activity when using the EC, but neither of these reached a level such as 5–10 %MVE which might be considered clinically relevant. Most of the muscles showed high levels of static muscle activity for both UC and EC and hardly any variation in muscle activity load, as almost no increase was seen in the median and peak levels.

Our hypothesis was that using EC could improve posture and reduce muscle activation during playing compared to UC. This idea is based on previous research showing that poor posture and excessive muscle activation can lead to pain and injury in musicians (Baadjou et al., 2017; Rousseau et al., 2021). The EC was designed to reduce head tilt, forward flexion, and static muscle activation in the neck and upper body. The unchanged static workload in the upper body muscles may be necessary to maintain accuracy in playing, as professional musicians are trained to use specific movement patterns and muscle loads. Thus, even adjusting the chin and shoulder rests may not change these established motor skills. We found that the adjustments of EC resulted in a change in the total height compared to UC, but the violinists may have repositioned the violin to compensate for the height difference. Measuring the violin angle between the two setups could provide further insight (Hildebrandt et al., 2021). Existing literature on ergonomic changes in violinists is limited, with conflicting outcomes and a population of 20 violinists being the most extensive study (Kok et al., 2019). Two studies found that

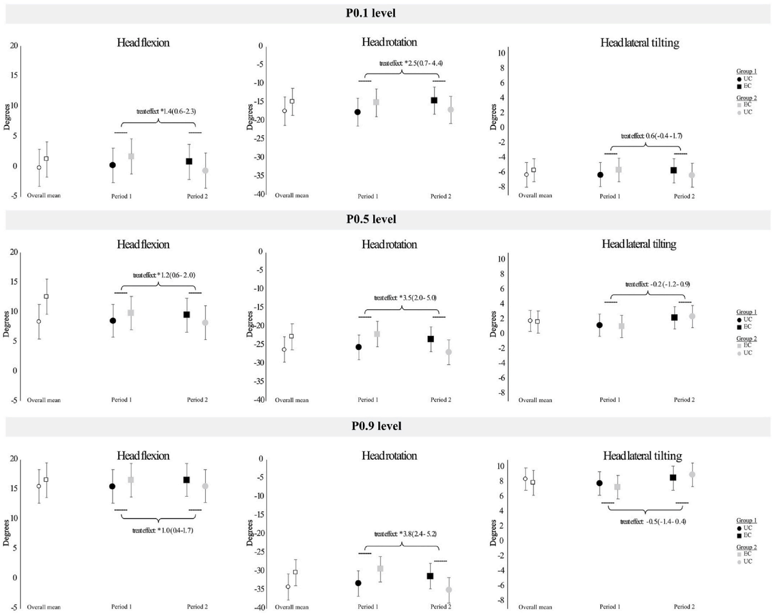


Fig. 4. Kinematic angles (°) with 95% CI for head and upper body posture: overall mean and the static, median and peak levels. Test periods 1 and 2 represent randomised playing order: UC-EC and EC-UC, respectively. The treatment effect is the difference between UC and EC.
*denotes p-value ≤0.05 between UC and EC.

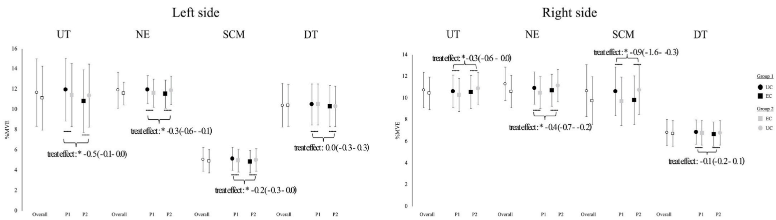


Fig. 5. Mean muscle activity (%MVE) and 95% CI for the total data set (Overall), periods 1 (P1) and 2 (P2) displayed bilaterally for UT (upper trapezius), NE (upper neck extensor), SCM (sternocleidomastoid), left anterior DT (deltoideus) and right medial DT.
*denotes p ≤ 0.05 between UC and EC with periods 1 and 2 as fixed variables. The treatment effect (treat) is the difference in mean %MVE (95% CI) between UC and EC.

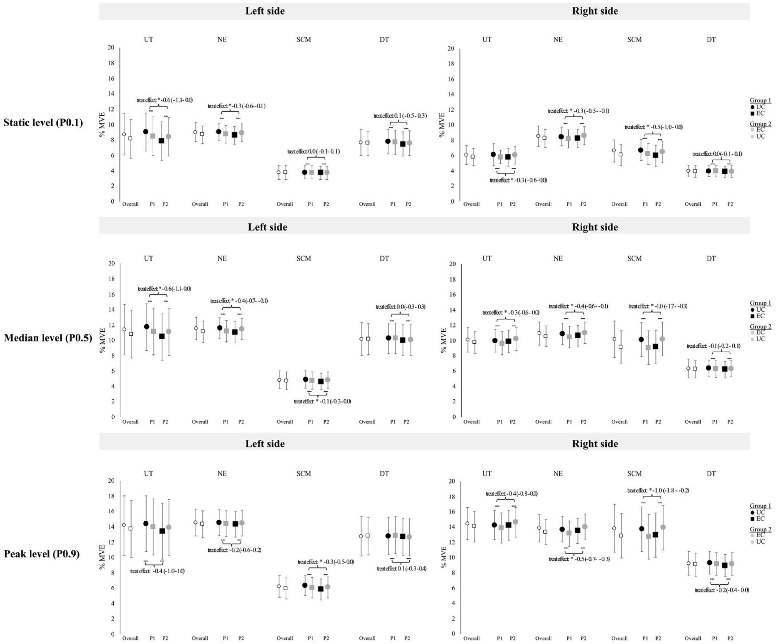


Fig. 6. Muscle activity (%MVE) with 95% CI for UT (upper trapezius), NE (upper neck extensor), SCM (sternocleidomastoideus) and left anterior DT (deltoideus), and right medial DT is presented for the static (P0.1), median (P0.5) and peak levels (P0.9), plus overall mean and periods 1 and 2. The treatment effect (treat) is the UC-EC difference in %MVE. *denotes $p \leq 0.05$ between UC and EC with periods 1 and 2 as fixed variables.

utilising different chinrests affected the pressure and force to hold the violin but also that muscle activity was changed by different repertoires (Obata and Kinoshita, 2012; Okner and Kernozek, 1997). Upon standardising the repertoire, we observed only small effects of the EC on the activity of the right SCM muscle. Additionally, we noted a slight increase in head extension, which can be associated with reduced pressure on the chinrest, as per Okner and Kernozek (1997). In this current study, the UT muscle activity is quite comparable to previous findings between 18 violinists playing the same music piece (Mann et al., 2021). One study found higher muscle activity in left SCM, DT, and UT compared to our results (Kok et al., 2019). However, this study used a population with and without pain. This could affect the comparison because violinists with pain generally show higher muscle activation and different movement patterns than pain-free violinists (Möller et al., 2018; Wolf et al., 2019).

The static muscle activity levels across all muscles on the left and right side of the body were generally 4–10 %MVE, which can be a risk factor for fatigue (Hagg, 1991). Compared to other occupations at risk of developing work-related disorders and with a high prevalence of pain, violinists have higher static levels and less variation (Blangsted et al., 2003; Dalager et al., 2019; Murray et al., 2016). Therefore, prolonged playing, as when a violinist practices all day or plays for up to 6 h in a concert, constitutes a considerable risk for fatigue and pain development.

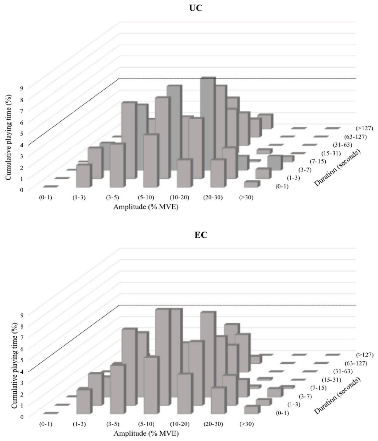


Fig. 7. Exposure variation analysis (EVA) of muscle activity in the right sternocleidomastoid (SCM) during UC and EC. The matrix shows the relationship between cumulative playing time (%), amplitude (muscle activity, %MVE) and length of time at each
amplitude level (seconds).

4.1. Limitations and strengths

Using the Vicon motion technology and Myon, wireless EMG has the benefit of permitting considerable freedom of movement for the participants allowing them to play and move naturally. The two weeks of familiarisation period is a strong element in this study design because the motor adaption of learning to use new ergonomic equipment, including adjustment to neck length and playing style, requires time and is associated too high compliance and acceptability (Mann, 2022).

However, the two weeks of focusing on an aligned neck position may have influenced our results because of a learning effect when playing with UC. It can take a human several hundred movements to learn a specific perturbation, while habitual behaviour can be restored within minutes (Jansen-Osmann et al., 2002; Shadmehr et al., 1998).

This study is one of the most extensive studies conducted on a homogenous group of pain-free professional violinists compared with other research (Chi et al., 2020; Rensing et al., 2018; Schemmann et al., 2018). The standardised protocol was tested for feasibility, and the robust crossover design allowed the participants to be their own controls (Wellek and Blettner, 2012).

4.2. Implications for further research

This EC might not be the tipping point for improving the physical work situation for violinists. Minimal changes in static muscle activity and head kinematics were observed using EC. Therefore, other organisational changes may be needed. Further research might examine whether violinists tend to reposition the violin in compensation when using new equipment and whether playing hours can be modified with longer and monitored breaks.

The study protocol can easily be adapted to other settings and other populations. In contrast to this study population, violinists with pain might benefit differently from this or other ergonomic changes due to their altered movement patterns (Möller et al., 2018; Wolf et al., 2019).

Objective measurements may show high static loads or no significant changes when using new ergonomic equipment, but positive subjective effects may still exist. Factors such as design, sound, and comfort can influence the decision when choosing ergonomic equipment. Future studies could include subjective factors to provide insight into what matters to individual performers, even if biomechanical measurements do not show any differences.

5. Conclusion

The present study was designed to determine the effect on upper-body muscle activity and kinematics when professional violinists changed to an "ergonomic" chinrest in a controlled laboratory study. Unfortunately, there was no substantially different kinematic or muscle activity between playing with UC or EC. For both setups, the head posture was left-rotated $>15^\circ$, $\leq 6^\circ$ flexed and left-bent 90% of the time. EC showed statistically lower muscle activity but of very small magnitude which did not relieve the overall high static muscle activity. The EC also reduced head rotation and extension by only a few degrees.

This study is the first comprehensive investigation of ergonomic equipment with a robust study design and a sizeable homogenous study sample. Future studies may investigate other initiatives to lower the workload demands.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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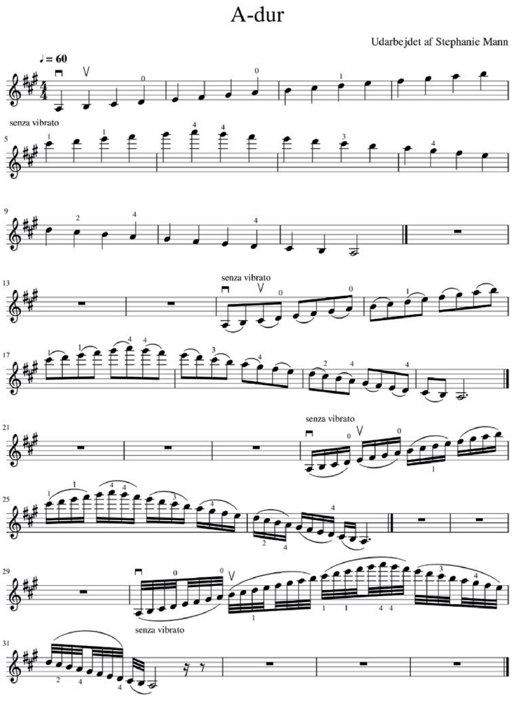
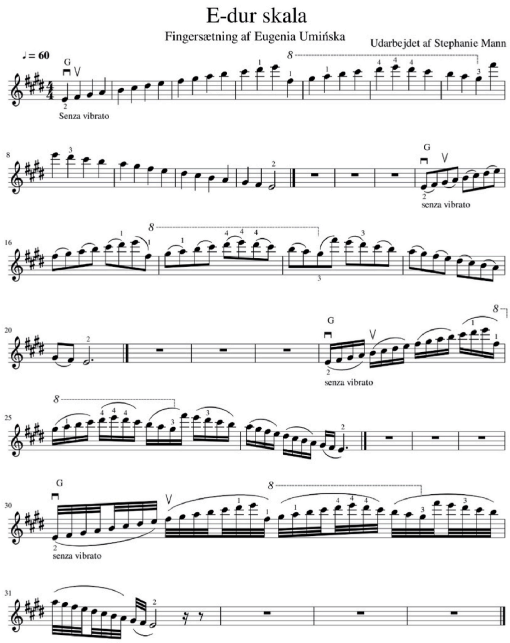
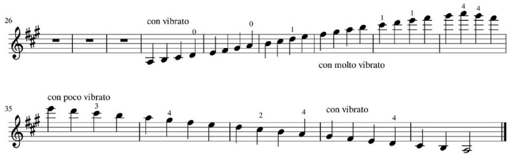
Appendix A1. Music scores for warm up



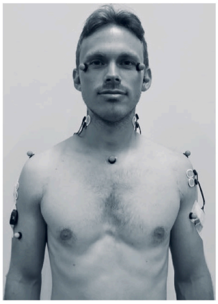


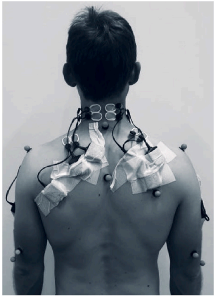
A major with vibrato.



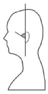
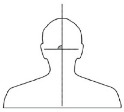
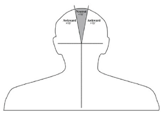
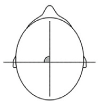
Appendix A2. : An excerpt of the music piece

Appendix B. The position of markers and electrodes for measuring neck, upper body kinematics and muscle activity in the neck and upper body. The reflective surface markers for Vicon were placed: 1) cantus bilaterally, 2) tragus bilaterally, 3) processus spinosi C7 and T5, 4) the jugular notch, 5) lateral borders of acromion bilaterally, 6) the right scapula, 7) trochanter major bilaterally, 8) lateral epicondyle bilaterally and 9) two markers on each upper arms





Appendix C. Definitions of the seven kinematic angles

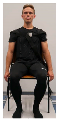
Angle	Description	
Head flexion	The angle between a line drawn from the Cyclops (midpoint between the left and right canthus) to the OCI (midpoint between the left and right tragus) and the vertical axis. (Negative is flexion)	
Head lateral tilting	The lateral angle between a line drawn from the OCI to the tragus, with the vertical line going through the OCI. (Negative is to the left)	
	Two categories were made from the Standard Evaluation of Static Working postures from ISO 11226 (ISO, 2000). The lateral head tilt was defined as neutral (<10°) and awkward (>10°). Percentage of the working time spent in these two categories will be calculated and used for evaluating UC and EC.	
Head rotation	The angle between a line drawn from the OCI to the Cyclops, with the anterior axis in the transverse plane. (Negative to the left)	
Trunk flexion	The angle between a line drawn from the spinousi C7 to the mid-point of the greater trochanters and the vertical axis. (Negative is flexion)	The 10s static aligned posture was used as baseline sitting posture and was withdrawn the calculated angles.
Thoracic trunk rotation	The angle between a line drawn from the sternum to the processus spinosi T5, with the anterior axis in the transverse plane. (Negative to the left)	

(continued on next page)

(*continued*)

Angle	Description
Left upper arm abduction	Between thorax vector and upper arm vector. Thorax vector from C7-T5. Upper arm vector from left acromion to left lateral epicondyle.
Right upper arm abduction	Between thorax vector and upper arm vector. Thorax vector from C7-T5. Upper arm vector from right acromion to right lateral epicondyle.

Appendix D. The six different MVIC tests for normalisation of the EMG signal

The participant is in a seated position with the arms flexed at 90° in a customized chair with the back straight and head in neutral looking straight forward. Resistance applied with straps at the elbow while doing arm flexion.	
The participant is seated with arms abducted at 90° in a customized chair with the back straight and head in neutral looking straight forward. Resistance applied with straps at the elbow while doing arm abduction.	
Empty can: Participant is seated with shoulders abducted at 90° in the scapular plane, internally rotated and elbow extended in a customized chair with the back straight and head in neutral looking straight forward. Resistance applied with straps at the wrist.	
Shoulder shrug: Participant is seated in a customized chair with relaxed shoulders, arms along the side, back straight and head in neutral looking straight forward. The participant was fixated to the customized chair with straps over the shoulders (acromion). Participant had to do a shoulder elevation as high as possible toward the ears against the resistance.	
Cervical Extension: Participant was standing against a wall and instructed to keep straight back, position the head in an anatomically neutral position and with the hands at the back of the head (the level of the external occipital protuberance). In this position the participant had to press against the hands with the neck and keep the jaw in.	
Cervical flexion: Participant was standing against a wall and instructed to keep straight back, position the head in an anatomically neutral position and with the palms on their forehead. In this position the participant had to press against the palms.	

Appendix E. Height adjustment in details for group 1 and 2

	Height adjustment (cm)			Height adjustment of the shoulderrest (cm)		
	Group 1 (UC-EC)	Group 2 (EC-UC)	Total	Group 1 (UC-EC)	Group 2 (EC-UC)	Total
	Median (Q1-Q3)	Median (Q1-Q3)	Median (CI)	Median (Q1-Q3)	Median (Q1-Q3)	Median (CI)
UC	11.3 (10.3–12.0)	11.3 (11.0–11.8)	11.3 (10.9–11.9)	5.2 (4.4–5.8)	5.2 (4.7–5.5)	5.2 (4.8-5-5)
EC	12.3 (11.6–12.9)	12.6 (12.2–13.03)	12.6 (12.2–12.8)	4.5 (4.3–4.6)	4.5 (4.2–4.9)	4.5 (4.4–4.6)

Appendix F. A descriptive table of the overall mean (containing both periods 1 and 2) muscle activity for the static rest and the music piece (%MVE) and 95% CI is displayed bilaterally for UT (upper trapezius), NE (upper neck extensor), SCM (sternocleidomastoideus), left anterior DT (deltoideus) and right medial DT

Setup	Left side		Setup	Right side	
	Static position	Music piece		Static position	Music piece
	UT	UT		UT	UT
	Mean [95% CI]	Mean [95% CI]		Mean [95% CI]	Mean [95% CI]
UC	10.0 [6.5–13.5]	11.7 [8.4–15.0]	UC	7.1 [5.2–8.9]	10.7 [8.3–13.1]
EC	8.6 [6-0-11.2]	11.1 [8.0–14.3]	EC	6.4 [4.9–8.0]	10.4 [8.9–12.0]
	NE	*NE*		*NE*	*NE*
	Mean [95% CI]	Mean [95% CI]		Mean [95% CI]	Mean [95% CI]
UC	8.5 [7.2–9.9]	11.9 [10.4–13.4]	UC	8.7 [7.4–10.0]	11.3 [9.8–12.9]
EC	8.1 [6.7–9.4]	11.6 [10.2–13.0]	EC	8.2 [7.0–9.3]	10.6 [9.1–12.1]
	SCM	*SCM*		*SCM*	*SCM*
	Mean [95% CI]	Mean [95% CI]		Mean [95% CI]	Mean [95% CI]
UC	2.8 [2.3–3.2]	5.1 [3.0–6.3]	UC	4.9 [3.7–6.1]	10.7 [8.3–13.1]
EC	2.7 [2.3–3.2]	4.9 [3.8–6.1]	EC	4.7 [3.4–5.9]	9.7 [7.5–12.0]
	DT	*DT*		*DT*	*DT*
	Mean [95% CI]	Mean [95% CI]		Mean [95% CI]	Mean [95% CI]
UC	13.0 [10.9–15.2]	10.4 [8.3–12.6]	UC	5.6 [4.5–7.0]	6.8 [5.6–8.0]
EC	12.6 [10.5–14.8]	10.4 [8.4–12.5]	EC	5.7 [4.6–6.7]	6.7 [8.9–12.0]

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Paper IV

The user experience of violinists playing with a novel ergonomic chinrest: An evaluation on motivation, usage behaviour, usability and acceptance

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Abstract

BACKGROUND: This study focuses on the user experience of a novel developed ergonomic chinrest (EC), customised to accommodate the individual violinist's anthropometry and playing style. The EC was recently tested for biomechanical effect, but the violin player's motivation, usage behaviour, usability and acceptability may be equally important.

METHODS: Thirty-eight professional violinists participated and evaluated motivation, user behaviour, usability and acceptance using a 5-point Likert scale and open-ended questions.

RESULTS: Participants showed high motivation hoping to improve posture, reduce muscle tension and enhance performance. Usage behaviour was also high, while product appearance, adjustment time, and sound impact were negatively evaluated. However, 37% planned to continue to use EC after the study.

CONCLUSION: Participants showed high motivation and usage behaviour but faced challenges with product appearance, adjustment time, and sound impact compared to their usual chinrest. Incorporating user feedback and addressing design and usability challenges can enhance the user experience.

Keywords: Ergonomics; music; neck; work performance

1. Introduction

Despite the widespread use of supportive equipment among musicians to increase comfort, enhance playing performance and alleviate pain [1] violinists still experience high levels of pain and musculoskeletal issues, ranging from 64.1% to 90% within the last year [2]. These issues primarily affect the neck and shoulder region, with the violin positioned on one shoulder leading to prolonged body postures with elevated upper arms, flexed elbow, and a rotated and flexed neck position [3–9]. The chinrest and shoulder rest are two supportive pieces of equipment commonly used by violinists to address these issues and improve stability for the violin to facilitate complex playing techniques [10]. Violinists typically play with both a chinrest (on the top of the violin) and a shoulder rest (positioned between the musician's left shoulder and the instrument's body) [11]. Despite the use of this supportive equipment, pain and discomfort remain prevalent among amateur and professional violinists [2,8,12,13] leading to behavioural consequences such as increased use of painkillers and modifications in their way of playing and holding their instruments [14]. Many violinists explore and experiment with ergonomic equipment such as chinrests and shoulder rests throughout their careers, aiming to find an optimal playing posture and enhance their comfort [15].

The scientific evaluations of supportive equipment for violinists have primarily focused on the impact on muscular workload and body posture [1]. Some recent studies have examined shoulder rest from a biomechanical perspective [5,16–18], while fewer have focused on the chinrest [19,20]. In a feasibility study, a new ergonomic adjustable chinrest (EC) made of plastic and used with a low shoulder rest was recently found feasible among violinists [15]. The EC was selected for testing due to the incorporated features allowing for customised adjustment to accommodate the individual violinist's anthropometry and playing style. Despite its promising design, the effectiveness of this new EC in comparison to violinists' usual equipment revealed only minor or no significant changes in muscle activity in the neck, throat, and shoulders, as well as in neck kinematics [21]. However, the user experience of employing this combination of ergonomic products among violinists remains largely unexplored [5,20], despite the significance of individual perceptions and the musician's choice and use of such products.

Introducing any new equipment would bring potential benefits, problems, and complexities and several aspects, such as motivation, usage behaviour, usability and acceptance, may influence the user experience [22,23].

Usability refers to the ease of use and how well a product meets the needs and expectations of the user to achieve specified goals with effectiveness, efficiency and satisfaction [24]. Therefore, it is important to include these perspectives to understand how an ergonomic product can support the health and well-being of musicians and how it can be improved to better meet musicians' needs.

Gaining an understanding of the user experience when using a new product will provide valuable insights into the behaviour of violinists, who often try new products [15]. This exploration may help to identify which potential facilitators or barriers that may arise when using a novel product [25].

The general lack of focus on the user experience of such equipment may well limit our understanding of factors that promote or hinder the use of ergonomic equipment for violinists investigated in ergonomic studies [5,19]

In the present study, we aimed to explore the user experience of violinists who used the novel EC with a low shoulder rest for two weeks. Through that experience, we wanted to learn about the potential user barriers and facilitators related to their motivation, usage behaviour, usability, and acceptability, when trying a new product.

2. Methods

2.1. Study design

This study is a descriptive evaluation of the user experience conducted alongside a randomised crossover trial that evaluated upper-body kinematics and muscle activity when using the EC compared to the violinists' usual chinrest and shoulder rest (UC) [21]. The study was performed in a setting very similar to the real life of a violinist trying a new ergonomic product for two weeks.

The Regional Scientific Ethics Committee stated that no ethical approval was required (S-20202000-87), and the trial was retrospectively registered at ClinicalTrials.gov. (NCT05604313).

2.2. Participants and Procedure

Participants were recruited from professional symphony orchestras in Denmark through an initial email to the orchestra managers. In addition, conservatory students in their final year of education and freelance professional violinists were invited through social media and word of mouth. A recruitment video on YouTube [26] was created and utilised in the recruitment process. We made it clear that participation was open to all interested violinists, irrespective of their personal preferences or opinions regarding ergonomic products.

The inclusion criteria required participants to be professional violinists aged 18 years or older proficient in speaking and writing Danish or English. Exclusion criteria included participants who were currently using the specific EC, reported pain symptoms >3 (rated on a numeric rating scale from 0 (no pain) to 10 (worst imaginable pain)), experienced recent trauma to the upper cervical spine or upper extremities within the past year, had a previous or planned shoulder/neck operation, had life-threatening health disorders, a pacemaker, or severe eczema on the neck and upper extremities.

All participants voluntarily participated and were provided comprehensive information about the study's purpose. They provided informed consent prior to their involvement.

The study procedure is illustrated in Figure 1. A baseline web-based questionnaire was used to assess participants' motivation to participate in the study and their previous experience with ergonomic equipment. Participants were then given the EC (Kréddle) and low shoulder rest (Kun Super rest violin 4/4) (Figure 1) for free via postal delivery and a self-administered two-week paper diary. Links to two YouTube videos were emailed to provide information about the project and how to assemble and adjust the EC, including instructions on head posture. The first video encouraged participants to use the EC during all their playing time [27,28], while the second video explained the adjustment of EC [28]. Participants completed a two-week familiarisation period with the EC, after which they recorded daily usability data on their confidence, adjustment, and emotions in a paper diary. The participants had to self-adjust the EC without any further help. In the evening, participants received a reminder text to prompt them to fill in the diary. A motivational phone call was made after one week to encourage continued participation.

The follow-up questionnaire focused on the usability of the EC, with self-reported questions on design, comfort and performance. Participants were randomly assigned to play with the EC and UC in the third week (test day), while upper-body kinematics, muscle activity, and sound were measured. Lastly, the participants were asked to blindly assess their sound recordings one month after the test (week 7).

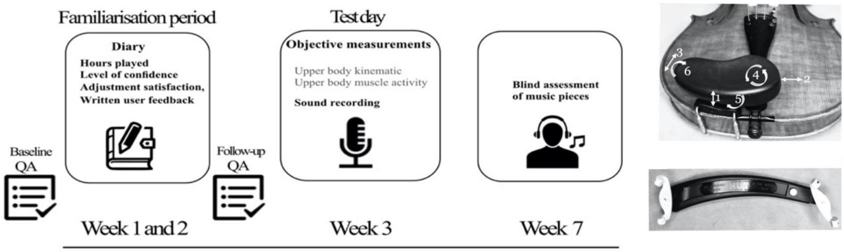

Figure 1. Timeline and overview of the procedures with questionnaires (QA), the two-week familiarisation period, test day in the randomised cross-over trial and the follow-up assessment of the music pieces. The objective measurements, coloured in grey, have been reported in an earlier study. The second picture illustrate the EC with all the different adjustments the low shoulder rest.

2.3. Outcomes

A 5-point Likert scale was used to evaluate motivation, user behaviour, usability, and acceptance – and in addition, open-ended questions were posed. The specific wording of the questions can be found in Appendix 1.

2.3.1. Motivation

The motivation to engage in this test of an EC was investigated in a baseline questionnaire using two different open-ended questions (Appendix 1).

2.3.2. Usage behaviour

During the familiarisation period, the diary was used to track usage behaviour, recording the number of playing days and the duration of each session using the EC or usual chinrest. The participants were encouraged to use the EC during all their playing time and every day. Adherence was calculated as days using the EC and the total duration of playing time with EC.

2.3.3. Usability

We used the International Organization for Standardization definition of usability as a framework and adapted its criteria for effectiveness, efficiency, and satisfaction [24]. Our analysis yielded insights on confidence, performance (effectiveness), and adjustments (efficiency). To evaluate overall usability satisfaction, we measured factors such as emotions, comfort, design, and sound, which collectively influence the user experience [29].

2.3.3.1. Confidence and performance

We used the confidence outcome to estimate the number of days it took participants to play the music sheets with confidence (a measure of success in using the product to achieve a specific goal). This information was obtained through daily diary entries using a 5-point Likert Scale. This study reports the number of days it took for participants to give a positive response ('fairly confident') two days in a row (Appendix 1).

The performance scores were calculated based on three questions (Appendix 1). The overall score was subsequently calculated based on the Disabilities of the Arm, Shoulder, and Hand questionnaire (DASH) score calculation method [30]. Performance questions about using UC were included in the baseline questionnaire, and questions about using EC were included in the follow-up questionnaire.

2.3.3.2. Adjustment

The adjustment level was determined based on the days participants spent before finding an adjustment that worked while playing and answering, ‘yes’ instead of ‘no’. This study will report the number of days it took for participants to consistently provide positive responses for a minimum of two consecutive days (Appendix 1).

2.3.3.3. Emotions

Emotions can be described as neurophysiological states that encompass thoughts, feelings, and behaviour. They are often characterised as positive when associated with a sense of pleasure and negative when associated with a sense of displeasure. The participants were encouraged to submit responses elaborating on their positive or negative experiences (emotions) using the EC through the diary [22].

2.3.3.4. Comfort

The comfort scores were derived from five questions outlined in Appendix 1. These questions were asked simultaneously with the performance questions, and the calculation of an overall score followed the same method used for the performance score.

2.3.3.5. Design

The follow-up questionnaire included an open-ended question that asked participants to compare the appearance of the EC to their usual chinrest (Appendix 1).

2.3.3.6. Sound

The sound was evaluated a month after the recording was made on the test day. Two miniature microphones (DPA-4063) were attached to the music stand in front of the participant. The recordings were made with a DPA-MPS6030 battery-driven power supply and an Olympus LS-10 stereo digital recorder. The signals were sampled at 44.1 kHz with 16-bit resolution, stored in an uncompressed WAV format, and later converted to MP3. Three recordings were made for each setup (UC and EC): A and E major scale (warm-up) and then one recording of the music piece (second movement from Mozart's violin concerto no. 5 in A major) that has been demonstrated to be a representative music piece for violinists [31,32]. After a month, each participant received an email with six randomised recordings of their performance labelled A-F to ensure blind assessment. For each recording, the participant had to indicate whether they thought the recording had been played with EC by answering "yes," "no," or "I don't know."

Furthermore, they had to answer questions about their technique, tone, string crossing, quality of performance, and musical expression and interpretation. The different questions were adapted from a study investigating factors influencing the performance quality of violinists [33].

2.3.4 Acceptance

The participants were asked whether they planned to use the EC after the project ended by answering "yes", "I will consider", or "no" (Appendix 1).

2.4. Data analysis

2.4.1. Quantitative data

Descriptive data are presented as quartiles (Q1-Q3) frequencies, percentages (%), means, and standard deviations (SD). The difference in performance and comfort scores between UC and EC was analysed using a paired t-test after checking for normality using a Q-Q plot. Although violinists may not be able to hear the sound/timbre associated with EC and UC, they may still distinguish between the audio files from each condition. Using a binomial probability test with n=6 (audio files) and p=0.05, we found a probability of 0.03 of distinguishing between the two conditions. Based on this probability, we expect 1.1 musicians to guess correctly or incorrectly on all six audio files. The differences in tone, string crossing, etc., were tested using a Wilcoxon sign rank test. Statistical significance was set to $p<0.05$, and all statistical analyses were conducted in STATA (version 17).

2.4.2. Qualitative data

Open-ended responses from the diary and QA will be analysed using content analysis to condense the raw data into global themes. The data were coded in their original language, and the main author read the responses repeatedly and independently to become familiar with the data. The themes were categorised into positive, negative, and general responses and further condensed into global themes [34]. The general comments were written as sentences that could not be categorised as negative or positive and seemed irrelevant regarding using EC.

3. Results

3.1. Subject characteristics

The study included 38 participants, consisting of 12 men and 26 women. All participants self-identified as professional violinists, with three being conservatory students (master/soloist class) and 35 being full-time working violinists, including symphony orchestra members, freelancers, and music teachers. They were 42.6 ± 12 years old and reported no pain at the time of inclusion.

Over half of the sample (63%) were currently very satisfied or satisfied using their usual chinrest, and seventy-four per cent of the participants had previous experience with trying another chinrest. Seventy-six per cent found the length of the familiarisation period appropriate. However, 79% usually only took days, hours, or minutes to decide if they liked a product. More detailed information, including the brand name of their usual chinrest and shoulder rest, can be found in Appendix 2 (a-b).

3.2. Motivation

All participants (n=38) answered the open-ended questions, and 58 comments and reflections were received for the motivation question and 77 for the essential aspects of trying an ergonomic chinrest. For both questions, the same four categories were identified as motivators: ergonomics, sound, health, and performance. An additional category for the motivation for participation was "to find a new or a better product than their usual" (n=16), while key aspects when trying a chinrest were "comfort and appearance" (Appendix 3).

3.3. Usage behaviour

The adherence to playing with the EC for each of the 14 days was high (median 85.7%, IQR 28%). Additionally, the total duration of playing time with the EC was also high (median 99.7%, IQR 16.6%). This indicates that the violinist spends almost all their playing time with the EC.

3.4. Usability

3.4.1. Confidence and Performance

The median time was two days (IQR 2) before answering "fairly confident" when asked about confidence.

As shown in Table 1, the performance score is significantly worse for EC than UC, with 15.6 points higher score for EC.

3.4.2. Adjustment

Finding an adjustment that worked by answering "yes" also took a median of 2 days (IQR2).

3.4.3. Emotions

The written user experience from the diary on EC was divided into positive, negative, or general comments. In total, 420 comments were given over the two weeks, with more negative (n=213) than positive (n=163) comments.

Week 1 comments covered 84 positives (median 3.0; IQR 3), 129 negatives (median 1.5; IQR 3), and 20 general comments (median 0.0; IQR = 1). Similarly, week 2 covered 79 positives (median 2.0; IQR 4), 84 negatives (median 2.0; IQR 3), and 24 general comments (median 1.0; IQR 1).

During the two weeks, one participant gave no comments, two gave no negative comments, and five gave no positive comments. Most comments were on adjustment and body posture, second most on pain and discomfort, and third most on sound. The distribution of comments on these three main issues can be seen in Figure 2. Figure 3 shows a flowchart with the total comments divided into barriers and facilitators related to the three themes.

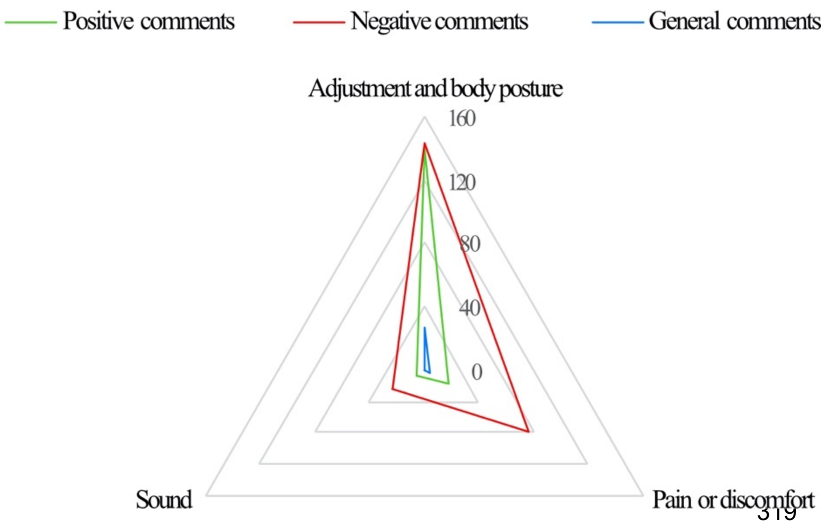

Figure 2. The radar chart shows, for both first- and second-week comments, the three themes and their distribution on positive, negative, and general comments and their internal relation.

Adjustment and body posture

Facilitators
- Not thinking about using the EC
- Feels like my usual chinrest
- Getting more comfortable with the adjustments
- Feel more body freedom in left/right arm
- Neck posture feels good (more aligned)
- Like the many possibilities with EC

Barriers
- Kun (shoulder rest) does not feel right = changing the angle of the violin and makes the violin too close to the collarbone
- Changing playing technique
- Less freedom in left arm/neck
- Feels disconnected from the violin
- Problems to use with different cloth
- Adjustment is time-consuming and difficult
- Needs to be disassembled before closing the violin case

Pain and discomfort

Facilitators
- Starting to feel less tired/tension in the muscles
- More relaxed compared to usual

Barriers
- Hurting on the collarbone
- Neck/jaw pain
- More tension in the left arm
- pain and discomfort in shoulderblades primarily the left shoulder

Sound

Facilitators
- Timbre better with EC
- Not a problem in the orchestra to hear the violin

Barriers
- Difficult to hear the violin in the orchestra because the ear is further away from the instrument.
- Feels it changes the timber
- Feels it dampens the sound

Figure 3. The three identified themes with different factors that can facilitate or be a barrier to using EC.

The most common complaint about the EC was that adjustments were time-consuming and complicated due to the many options available. A significant barrier to using the EC was the time required for disassembly, storage in the violin case, reassembly, and adjustments, which detracted from practice, according to one participant:*" You must just get your act together to get started because there are so many things you need to adjust. You just want to be able to play right away. Feel like you are wasting your practice time." (Female, 46)*

Or another violinist wrote: *"I get impatient having to put it on when using" (female, 29 years old)*

Furthermore, many participants found the shoulder rest (Kun) problematic because it changed the angle of the violin or did not give the comfort and support, they felt they needed.

"Bad angle of the violin because of the shoulder rest" (female, 50)

"Tried different adjustments of the chinrest but ended with approximately the same as before. Can't find the optimal angle for the shoulder rest, though. Lacks support on top of the shoulder". (Female, 23)

The theme of pain and discomfort also revealed that several participants experienced discomfort in their collarbone due to the placement of the violin and the low shoulder rest.

"The violin is placed badly on the collarbone, and I really want to raise the shoulder rest, as it hurts. But I don't do it. It is also not comfortable to play so "far down" on the arm. I'm getting tension in my left elbow that I have not had before." (Female, 37)

Fewer participants (n=11) made a negative or a positive (n=7) comment about the timbre. The negative comments were mainly that the timbre changed or that it was more difficult for them to hear their violin when sitting in the orchestra.

"One minus: The quality of the timbre is not top notch." (Male, 46)

In contrast, most of the positive comments stated that the EC improved the timbre of the violin, with some explicitly noting this when playing scales: *"The sound is definitely better with the Kréddle!" (Female, 64)*

Positive comments about adjustments and body posture noted increased freedom in the body, neck, and left arm and the ability to adjust to the individual player: *"The adjustment takes some time because Kréddle has so many options. It´s a great advantage, but it does take some time to find the right position. It improves the general posture, especially the neck". (Male, 33 years old)*

The positive comments about pain and discomfort were primarily that the discomfort that occurred at the beginning of the two weeks disappeared or decreased during the days:

"Tired in the neck, but not the same pain as with my own. I think the new head/neck position is good! Especially the better height of the chinrest helps 😊." (Female, 50)

General comments were about where or how much they played or which specific adjustments they made on the EC.

3.4.4. Comfort

In Table 1, the comfort score is shown. We did not find any difference in the comfort score between both setups.

Table 1. Comfort and performance scores for both UC and EC were based on five and three questions, respectively. UC: Usual chinrest and shoulder rest and EC: Ergonomic chinrest including low shoulder rest. A score >0 indicates a negative or reduced comfort or playing performance (a scale ranging from 0-100). * Indicate significant difference between UC and EC in performance score at p=0.03 including CI (confidence interval).

	UC Mean (95%CI)	**EC** Mean (95%CI)	**UC-ECΔ** Mean difference (95%CI)
Comfort	31.2 (25.4-36.9)	37.0 (31.3-42.6)	-5.8 (-14.1 – 2.5)
Performance	14.9 (8.3-21.5)	30.5 (22.7-38.3)	-15.6 (-25.3- 5.9)*

3.4.5. Design

All participants left either a positive or negative comment about the appearance of the EC. Sixteen participants' comments could be categorised as negative and nine as negative but not problematic. Examples from two participants that sum up the general negative feedback:

"Unfortunately, not as nice as my own chinrest; I think it is more beautiful with wood." (Female, 25)

"I think it looks strange that it is "floating" so high above the violin. Not nice. It looks cheaper than my own chinrest." (Female, 46)

The ones that did not find it problematic wrote:

I don't like plastic material, but the idea is good and can also be refined to fit different chins." (Female, 50)

"Fine, but not as beautiful as my own." (Male, 33)

Eight participants stated that *"it is okay",* and five participants' comments could be defined as genuinely positive about the appearance of EC, stating:

"It is more modern. Discreet" (Female, 36)

"It's unconventional, but I like it very much." (Male, 38)

3.4.6. Sound

Of 37 violinists, 12 (32.4%) could distinguish between the two conditions across all six audio files. Specifically, four participants guessed correctly for all six audio files, while eight guessed incorrectly for all six. The p-value was <0.001, indicating that the null hypothesis can be rejected at a 5% significance level. Additionally, the 95% confidence interval for the actual probability of success was 0.18 to 0.50. In the blind assessment, no overall differences were detected between UC and EC regarding technique, string crossing, tone or musical expression and interpretation. Only "quality of performance" showed a significant difference between UC and EC (p=0.02), with more participants scoring "bad" for EC than UC (fig. 4).

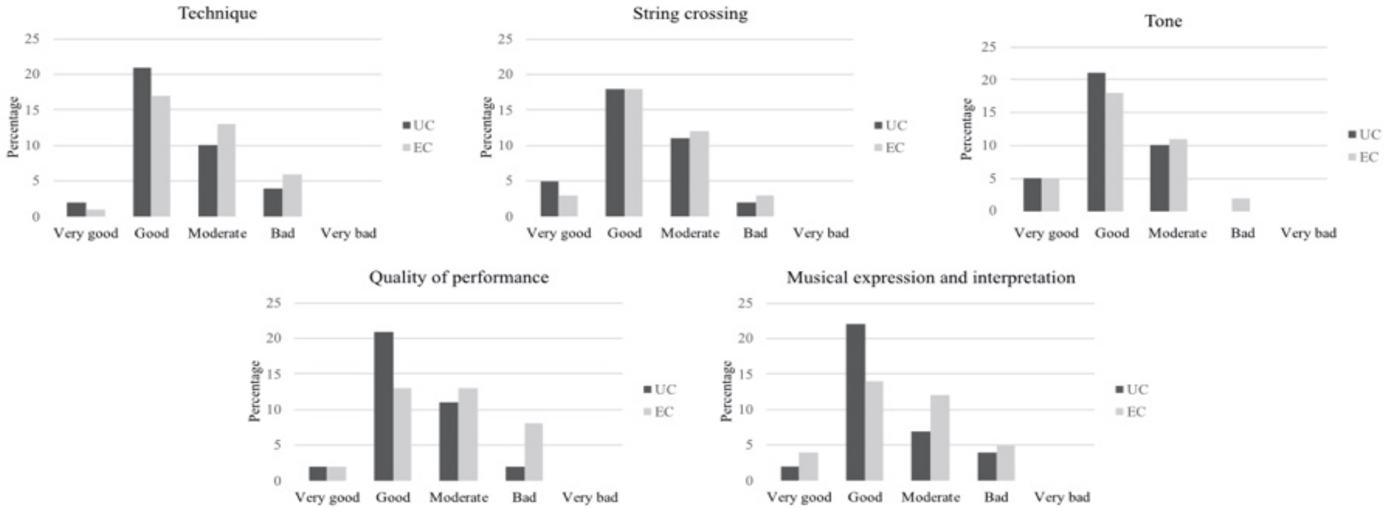

Figure 4. Showing the results in the blind assessment for the scoring of the technique, tone, string crossing, quality of performance, and musical expression and interpretation. UC: Usual chinrest and shoulder rest and EC: Ergonomic chinrest including low shoulder rest. Only the quality of performance showed a significant result (p=0.02) between UC and EC.

3.5. Acceptance

In total, 37% (n=14) of the participants wrote that they would continue to use the EC, 29% (n=11) said they will not, and 34% (n=13) are considering using the EC later.

4. Discussion

This study examined user experience by gaining insight into the motivation, behaviour, usability, and acceptability of professional violinists using the EC for two weeks. Thirty-eight professional violinists were motivated to join the study to improve body posture and reduce muscle tension. They showed high usage and became confident in only two days. However, usability issues negatively impacted their experience, resulting in a 15.6% decrease in performance scores and a lower sound quality. Although the diary generally received many negative comments, 37% of participants expressed their desire to continue using the EC. The appearance of a product can affect performance [35], highlighting the importance of considering aesthetics when designing it. In this study, the EC design received more negative feedback than positive, which may have influenced the performance score [36]. This knowledge can be used to refine the EC's design process. However, the negative feedback may not accurately reflect the overall user experience due to negativity bias. Participants may focus more on negative elements because they “stand out more” immediately than the positive ones and are referred to as "usability flaws" [37–39]. Many positive comments with similar themes as the negative ones were obtained during the study, indicating a shift over time as participants became more accustomed to the adjustments with less pain and discomfort. Time and difficulty required for adjustment are major barriers to using the EC. The complexity of a new product can reduce its evaluation due to the learning cost needed to understand it [40]. Though the included violinists quickly adjusted and felt confident, this period can still be long for those accustomed to making decisions within a few hours or minutes. Hence, it may be relevant to conduct a study focusing on musicians' initial impressions of the product, including its appearance and anticipated problems, and then conduct a follow-up evaluation after a shorter period to assess their typical decision-making process [41]. The study did not measure musicians' anticipated performance, comfort, or immediate reaction to the appearance of EC, which could have provided another insight into positive and negative design issues before use [42]. However, several usability outcomes in this study are measured over time, offering insight into how users adapt to EC. Usability includes various methods to measure effectiveness, efficiency, and satisfaction. This study did not measure error rates, precision, or time to complete tasks before the two-week period, which could have offered further insights during usability testing.

Additionally, the participants included in the study were non-injured, which may have resulted in a negative bias towards the product's complexity. In hopes of finding a solution to keep playing, injured violinists may prioritise other aspects over the product's complexity [43]. Despite the potential negativity bias, it is important to acknowledge that the negative feedback received regarding the product is critical and holds valuable insights that can significantly influence the user experience. Factors such as pain issues, the use of the shoulder rest with this EC, and the sense of disconnection between the player and the violin highlight areas that need to be addressed in the design process when considering the factors that impact the user experience.

The violinists demonstrated better-than-chance ability to distinguish between EC and UC audio files, showcasing their trained musical ability to differentiate between sounds and timbre. This may be due to the significant difference between UC and EC, with more negative scoring for EC in “quality of performance”. However, it is important to note that out of the twelve participants, only four accurately identified the sound associated with EC, thereby introducing an element of uncertainty regarding the precise influence of EC on the auditory experience. In addition, a prior study supports that timbre could be altered by different shoulder rests, with variation depending on the violin used [43]. The results of this study suggest that changing the chinrest and shoulder rest may impact the timbre and overall performance quality. Further investigation is warranted to determine whether the EC, the low Kun shoulder rest, or the combination influences timbre. This highlights the need for designers of EC to consider these variables during the design process.

By addressing concerns related to design, adjustment time, sound changes, pain, shoulder rest compatibility, and the sense of disconnection in the design process, it might be possible to create a chinrest that not only meets the ergonomic needs of the users but also enhances their overall musical experience.

Strength and limitations

This study answers the research question by combining information from questionnaires and written user feedback (open-ended questions), strengthening the identification of needed improvements of the EC.

While this study's high compliance and adherence rates are encouraging, it may not entirely reflect real-life usage. To ensure user satisfaction, it is important to consider design factors such as ease of use and comfort. This is particularly crucial given the relatively short timeframe in which musicians often evaluate a product's usefulness, which typically ranges from minutes to hours or a few days.

One limitation of this study is that the motivation questions need more specific theoretical underpinnings. Additionally, certain usability outcomes were developed solely for this study, indicating a need for further validation and standardisation. While it is a strength that the applied questionnaires are tailored to the product and cover sound, design, and emotions towards EC, it lacks well-established standardisation like the System Usability Scale [44]. Therefore, the results must be interpreted cautiously, as they may not be directly comparable to those obtained using a standardised scale. Moreover, this study did not extensively explore demographic factors such as age (visual acuity) and gender (physical abilities, anthropometry, communication, and decision-making processes), which may have influenced the interactions with the EC [45]. Insight into these aspects might have ensured that the product is accessible and usable for many users. However, the high external validity of our study is evidenced by the representative sample of professional musicians, which includes a higher proportion of women and an average age.

5. Conclusion and perspective

In conclusion, professional violinists demonstrated high usage behaviour with the EC, hoping to improve posture, reduce muscle tension, and enhance performance. However, various usability factors affecting the user experience of EC were identified, including design, adjustment time, performance and sound compared to their usual ergonomic product. Notably, 37% of violinists expressed an interest in continuing to use EC after participating in this study. Understanding the key factors influencing performance can assist violinists in making informed product decisions, ultimately increasing satisfaction and performance. Furthermore, product developers can integrate human factors considerations into the design process to meet users' needs and enhance the overall user experience. This study also contributes to the ergonomics and human factors field by enhancing the understanding of how individuals interact with products and technology, ultimately driving the development of safe, efficient, and user-friendly products.

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Appendix 1

Aim	Question	Answer
Motivation	(1) "Why are you motivated to participate in this project?" and (2) "What is the most important aspect for you when testing a new chinrest?"	Two open-ended questions.
Usability	*Effectiveness* <u>Confidence level:</u> "How confident are you playing with Kréddle? Very confident means that after several days you can still play the scales and the piece of music sent to you" <u>Performance:</u> 1) "Have you had difficulty playing your violin?" 2) "Have you had difficulty using your normal technique when playing?" 3) "Have you had difficulty playing as well as you would like to?"	Reported on a 5-point Likert scale (5= very confident, 1=not very confident). The questions were answered on a 5-point Likert scale, with options ranging from no problem to impossible.
	Efficiency <u>Adjustment:</u>	"Yes" or "No"

	"Have you found an adjustment of Kréddle that is working for you?"	
	Satisfaction Emotions: 1) "What are your immediate reactions using Kréddle? It can be about how the adjustment works for you with Kréddle, how you find the usage of Kréddle or general thoughts. Both positive and negative descriptions will be valuable for the project." 2) "If you haven't used Kréddle then just write why not"	Two open-ended questions.
	Comfort: 1) "How comfortable was playing with UC/EC in the last 14 days?" 2) "How comfortable was the height of UC/EC (with your chosen adjustment)?" 3) "How comfortable was the configuration of UC/EC that you have chosen?" 4) "How comfortable was the size of the chinplate of UC/EC?", 5) "How comfortable was the chinrest surface against your skin?"	The questions were answered on a 5-point Likert scale, with options ranging from very comfortable to very uncomfortable.
	Design: "What do you think of the appearance/design of the Kréddle chinrest compared with your usual chinrest?".	Open-ended question
	Sound: 1) "How does your technique sound overall?"	The questions were answered on a 5-point Likert

	2) “How is the tone of your violin playing in relation to fulness and power?” 3) “How does your string crossing sound? (in relation to controlled and smooth)?” 4) “How is your overall perception of the quality of your performance?” 5) “How is your musical expression and interpretation?”	scale, with options ranging from very good to very bad.
Acceptance	“Are you considering using the Kréddle from now on?”	“Yes, and I will use it with a shoulder rest”, or “I will consider changing at some point”, or “No, I prefer my usual chinrest”

Appendix 2 (A-B).

A The participant's previous experience and current view on trying EC

Different chinrests tried during the years (numbers)	
1	2
2-4	18
5-9	10
10 or more	8
Satisfied with current chinrest (numbers)	
Very satisfied	9
Satisfied	15
Neither	12
Dissatisfied	2
Very dissatisfied	0
Satisfied with the selection of chinrest in stores/online (numbers)	
Very satisfied	1
Satisfied	7
Neither	29
Dissatisfied	1
Very dissatisfied	0
Decision making when trying out new chinrest (numbers)	
Weeks	8
Days	16
Hours	5
Minutes	9
The length of the familiarization period (Follow-up QA), numbers	
Short time	4

Appropriate	29
To long	5

B

Overview of the brand names of chinrest/ shoulder rests the 38 violinists usually play with.*one participant used both brands (shoulder rest).

Brand	Chinrest (N)	Brand	Shoulder rest (N)
Dolfin	1	Acoustagrip soloist	1
Gewa	4	Bon Musica	1
Don't know	33	Dolfinos	2
		The Pedi Elegante	1
		Foam	1
		Kun*	14
		Pirastro korfker	7
		Libero de luxe	1
		Mach One	2
		Resonans	1
		Wolf*	4
		No name, don't know	4

Appendix 3

The table displays the results of the open-ended questions with examples. Four categories (ergonomics, health, sound, and performance) were identified for both questions. The motivation question had one additional category ("to find a new or better product than their usual"), while the essential aspects question had two additional categories (comfort and appearance). The identified categories and examples are shown in the table.

Open-ended comments about participants motivation to be a part of testing an ergonomic product

Category	N (%)	Examples
Ergonomics: Working posture	17 (45%)	*"Unsatisfied with my violin posture. I think it takes too long to get the violin in place before I play and I'm never really satisfied. Tired of getting a headache because I may have pressed down in the chinrest to hold on to the violin.... "*
Find a new product	16 (42%)	*"I haven't found the best one yet"* *"I hope to find a new system that works better than the one I currently use"*
Health: less muscle tensions	15 (39%)	*"I sometimes experience problems with my neck, so it could be interesting if this chinrest could help a little"* *"Because I want to test whether I can play without pressing my jaw so much"*
Sound	5 (13%)	*"If it doesn't have negative influence on the sound (muting the violin)"*
Performance	5 (13%)	*"Freedom of using my hands ..., freedom of moving left arm/shoulder"* *"I want to try a new chinrest because I want to test new possibilities and find out if there is more to be gained in relation to my playing, my health and my instrument."*

Open-ended comments about important aspects when trying a chinrest

Category	N (%)	Examples
Comfort	12 (32%)	*"That it sits well and I can hold my violin comfortably"*
Product material and apperance	7 (18%)	*"The material must be cleanable"* *"I would prefer a chinrest in wood, because it gives a better sound and doesn't "slip" so much in the heat"* *"That the material does not irritate the skin"* *"The look"* *"Soft edges"*

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