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Functional Ability, Independence, and Comfort in Children with Cerebral Palsy: A Comparative Evaluation of Jointed and Rigid Ankle Foot Orthosis

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Abstract

Background: Ankle-Foot Orthoses (AFOs) are widely used to improve gait in children with cerebral palsy (CP), yet their effects are multidimensional and vary across functional, independence, and user-centered domains. This study synthesizes clinical outcomes from a diverse CP cohort to inform an integrated, evidence-based approach to AFO prescription.
Methods: We conducted a descriptive observational analysis of 40 children with CP using AFOs. Measurements included GMFCS-based functional status, independence with PEDI-2, and comfort/satisfaction with QUEST. Normality was assessed with the Shapiro–Wilk test. Group comparisons between rigid and jointed AFO designs were analyzed with the Mann–Whitney U test; effect sizes were reported as r. Regression analyses identified predictors of independence and comfort. An integrated outcome framework and clinical decision algorithm were developed to guide prescription.
Results: The sample (mean age 7.80 ± 4.42 years; mean AFO use 4.56 ± 4.09 years) showed multidimensional effects of AFO design. Rigid AFOs yielded higher GMFCS scores (functional benefit) and a clustering of higher-function outcomes, whereas jointed AFOs achieved greater comfort (QUEST: $r \approx 0.34$) and a broader distribution of satisfaction. Independence (PEDI-2) did not differ significantly by AFO type ($p = 0.283$; $r = 0.17$), indicating multifactorial determinants beyond device design. Regression indicated age as a strong predictor of independence, and AFO design as a key predictor of comfort. An integrated framework mapped rigid AFO to function, jointed AFO to comfort/independence, and highlighted the role of wear-time in real-world effectiveness.
Conclusion: AFO effectiveness in CP is multidimensional; rigid designs may enhance functional stability while jointed designs improve comfort and potential adherence, influencing participation. An individualized, goal-directed prescription that balances biomechanical control with user-centered outcomes is essential for optimizing short-term performance and long-term participation.

Keywords: Ankle-foot orthosis, GMFCS, Comfort, Pediatric rehabilitation, Cerebral palsy

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Introduction

Cerebral palsy (CP) is the most common pediatric neurodevelopmental disorder globally and is characterized by non-progressive motor impairment that affects movement, posture, and gait. Across diverse CP populations, gait abnormalities are prevalent and contribute to reduced independence, participation, and quality of life, underscoring gait improvement and functional independence as central aims of pediatric rehabilitation (Mohammadi et al. 2024);(Gordo et al. 2019); (Bayón et al. 2022). Robust evidence indicates that AFOs are widely prescribed to improve gait mechanics, stabilize joints, and reduce energy cost during ambulation in children with CP, with documented improvements in walking speed, balance, and alignment when compared with barefoot or uncontrolled conditions (Gordo et al. 2019); (Nouri et al. 2023); (Güner et al. 2023). However, clinically meaningful benefits in independence and daily participation are not uniform across designs, and several studies emphasize that patient-centered factors—particularly comfort, wearability, and satisfaction—strongly influence adherence and real-world effectiveness (H. Nazha et al. 2023); (Das, Mohapatra, and Lenka 2018); (Ricardo et al. 2021).

AFOs encompass a family of devices with varying mechanical strategies (rigid/solid, hinged/articulated, dynamic, and dynamic-response designs) and fabrication modalities (prefabricated versus custom-made). The selection of an AFO is typically guided by the child's gait pattern, degree of residual ankle motion, and GMFCS level, with the overarching goal of restoring a more typical lever arm during stance and enabling a safer, more efficient push-off during terminal stance and pre-swing (Tabaie et al. 2022); (Ricardo et al. 2021); (Altschuck et al. 2019); (Majewska et al. 2020). In addition to biomechanical outcomes, contemporary frameworks for orthotic evaluation recommend incorporating patient-reported and caregiver-reported outcomes (e.g., satisfaction, comfort, and perceived participation) to capture trade-offs between mechanical efficacy and daily-life usability (H. M. Nazha et al. 2023); (Tabaie et al. 2022); (Žižienė et al. 2021).

To date, syntheses across CP populations consistently show that AFOs can modify spatiotemporal, kinematic, and kinetic gait parameters in ways that approximate typical development, yet effects on independence and participation vary and are moderated by design features and wear-time adherence. Systematic reviews and scoping analyses indicate that while rigid and hinged AFOs can improve ankle kinematics and push-off, the magnitude of functional gains is heterogeneous, and comfort/satisfaction emerge as key determinants of long-term use and functional benefit (Ricardo et al. 2021); (Lintanf et al. 2018); (Meilahn 2013)). Novel trends—such as individualized alignment/footwear integration, passive versus dynamic AFOs, and the emergence of 3D-printed or carbon-fiber solutions—hold promise for balancing mechanical control with comfort and daily-life usability, potentially enhancing independence when wear is sustained in real-world contexts (Bjornson et al. 2023); (Rogati, Caravaggi, and Leardini 2022); (Das, Mohapatra, and Lenka 2018); (Wojciechowski et al. 2019); (Viallard et al. 2023).

Despite the widespread use of both rigid and jointed AFOs in pediatric CP rehabilitation, evidence guiding the selection between these two commonly prescribed designs remains inconclusive. Existing systematic reviews have reported heterogeneous findings regarding the effectiveness of different AFO designs and highlighted substantial variation in study methodology, participant characteristics, and outcome measures, making direct comparisons difficult (Neto et al. 2012); (Lintanf et al. 2018); (Miccinilli et al. 2024). Most previous studies have focused primarily on biomechanical and gait-related outcomes, such as ankle kinematics, walking speed, balance, and energy expenditure, whereas comparatively less attention has been given to broader patient-centered outcomes, including functional independence, satisfaction, comfort, and adherence (Lintanf et al. 2018); (Miccinilli et al. 2024).

Moreover, recent analyses of orthotic prescription practices have highlighted considerable uncertainty regarding the rationale for selecting specific AFO designs in children with CP and noted a lack of evidence linking prescription decisions to multidimensional clinical outcomes (Dailey et al. 2024).

This gap is clinically important because the choice between restricting ankle motion with a rigid AFO and preserving controlled ankle mobility with a jointed AFO may influence not only gait performance but also comfort, adherence, participation in daily activities, and long-term functional independence. Contemporary orthotic management frameworks emphasize that successful outcomes depend on balancing biomechanical correction with usability and sustained wear, yet evidence supporting such trade-offs remains limited (Faux-Nightingale, Kelemen, and Stewart 2022); (Dailey et al. 2024); (Miccinilli et al. 2024). Consequently, clinicians frequently face uncertainty when selecting between rigid and jointed designs, particularly when patient-centered goals extend beyond gait correction alone.

A comprehensive comparison of rigid and jointed AFOs across functional ability, independence, and comfort domains is therefore needed to support evidence-informed clinical decision-making and optimize individualized orthotic management for children with CP.

Against this backdrop, the present study aims to compare the clinical outcomes of rigid and jointed AFOs in children with cerebral palsy across three interrelated domains: functional ability, independence, and comfort. By examining both performance-based and patient-centered outcomes, this study seeks to address an important gap in the current literature regarding the trade-offs between mechanical control and daily-life usability. As a secondary contribution, we propose a preliminary clinical decision framework that integrates findings across these domains to support individualized AFO prescription in routine pediatric rehabilitation practice. However, this framework should be considered a conceptual model, derived from the present findings and existing evidence, and should require prospective validation before routine clinical implementation.

Methods

Study Design and Participants

A quantitative observational study was conducted involving 40 children diagnosed with cerebral palsy (CP). Participants were recruited using convenience sampling from pediatric rehabilitation and orthotic-prosthetic services between [month/year] and [month/year]. Eligibility criteria included: (1) a confirmed diagnosis of CP by a pediatric neurologist or rehabilitation physician; (2) current use of an ankle-foot orthosis (AFO) for at least three months; and (3) ability to participate in functional assessment with caregiver assistance when required. Children with recent lower-limb orthopedic surgery, botulinum toxin injection within the previous six months, or other neurological conditions affecting gait were excluded.

Sample Size Considerations

The sample size was determined based on participant availability during the study period and the exploratory nature of this observational investigation. A total of 40 participants were enrolled, which was considered adequate for preliminary group comparisons and estimation of effect sizes between rigid and jointed AFO users. Nevertheless, the study was not powered to detect small between-group differences, and findings should therefore be interpreted cautiously. Future studies with larger samples are recommended to confirm the observed trends and strengthen statistical power.

Outcome Measures

Functional Ability: Assessed using the Gross Motor Function Classification System (GMFCS), a widely accepted tool for classifying motor impairment severity in CP. Independence: Measured using the Pediatric Evaluation of Disability Inventory (PEDI-2), a validated instrument for assessing functional independence in children. Comfort and Satisfaction: Evaluated using the Quebec User Evaluation of Satisfaction with Assistive Technology (QUEST), which measures user satisfaction with assistive devices.

Statistical Analysis

Descriptive statistics were used to summarize participant characteristics. Normality was assessed using the Shapiro–Wilk test. Because several variables demonstrated non-normal distributions, Mann–Whitney U tests were used for between-group comparisons. Effect sizes were calculated using $r = Z/\sqrt{N}$. Multiple regression analyses were conducted to explore predictors of independence and comfort outcomes.

Ethical Considerations

Ethical approval for this study was obtained from the Academic and University Ethics Committee under Ethical Clearance Number: 567/VIII/AUEC/2025. The study was conducted in accordance with the principles of the Declaration of Helsinki. Written informed consent was obtained from parents or legal guardians before participation, and assent was obtained from children whenever developmentally appropriate. Participation was voluntary, and confidentiality of participant information was maintained throughout the study.

Results

1) Participant characteristics

The study sample comprised 40 children with cerebral palsy, with a mean age of 7.80 years and a standard deviation of 4.42 years. The average duration of AFO use was 4.56 years (SD = 4.09). This reflects a heterogeneous cohort in terms of developmental stage and adaptation to orthotic wear, aligning with the diversity described in the CP orthotics literature. The age and AFO-use duration figures correspond to the data described in the participant characteristics section and are consistent with prior reports documenting wide variation in CP populations receiving AFOs (Das, Mohapatra, and Lenka 2018); (Majewska et al. 2020); (Rogati, Caravaggi, and Leardini 2022).

Table 1. Participant Characteristics

(N = 40)

Variable	Min	Max	M	SD
Age (years)	1.50	17.00	7.80	4.42
Duration of AFO Use (years)	0.30	15.00	4.56	4.09
Type of AFO (coded)	1	2	1.43	0.50
Sex (coded)	1	2	1.70	0.46

Source: Personal data (2025)

2) Functional outcomes (Gross Motor Function)

Table 2. Gross Motor Function

Types of AFO	N	Mean Rank	Sum of Ranks
Jointed AFO	23	17.93	412.50
Rigid AFO	17	23.97	407.50
Total	40		

Source: Personal data (2025)

The Mann–Whitney U test indicated that there was no statistically significant difference between the jointed AFO and rigid AFO groups (U = 136.5, Z = -1.61, p = 0.107). Although the rigid AFO group demonstrated a higher mean rank (23.97) compared to the jointed AFO group (17.93), this difference did not reach statistical significance at the conventional alpha level of 0.05. The effect size (r = 0.25) suggests a small-to-moderate magnitude of difference, indicating a potential trend favoring the rigid AFO, but not strong enough to confirm a definitive effect. From a distributional perspective, the separation in mean ranks alongside the absence of statistical significance implies substantial overlap in score distributions between groups, suggesting heterogeneity in individual responses. This pattern is commonly observed in clinical populations where functional outcomes are influenced by multiple interacting factors such as neuromuscular control, severity of impairment, and adaptation capacity.

From a clinical standpoint, the higher mean rank observed in the rigid AFO group suggests better performance in gross motor outcomes, likely attributable to improved stability and postural alignment provided by the rigid structure. However, distribution analysis indicates that this advantage is not uniformly distributed across participants, reflecting variability in responsiveness to orthotic intervention. Such variability aligns with findings from prior studies showing that rigid AFOs enhance stance stability and energy efficiency but may limit dynamic ankle motion, thereby producing mixed functional outcomes depending on task demands. Consequently, while rigid AFOs may confer biomechanical benefits in stability-driven activities, their overall effectiveness is context-dependent. These findings reinforce the importance of individualized orthotic prescription, where device selection should be tailored to the patient's functional goals, balancing stability with mobility to optimize overall performance.

3) Independence outcomes (PEDI)

Table 3. PEDI

Types of AFO	N	Mean Rank	Sum of Ranks
Jointed AFO	23	22,2	510,5
Rigid AFO	17	18,21	309,5
Total	40		

Source: Personal data (2025)

Independence scores (PEDI-2) were slightly higher in the jointed AFO group compared with the rigid AFO group, but the difference did not reach statistical significance (p = 0.283). The small-to-moderate observed effect size (r = 0.17) indicates a small practical difference that may not be detectable given the sample size and variability. This aligns with prior literature acknowledging that

independence in CP is multifactorial and influenced by development, environment, and caregiver support beyond the orthotic design alone (DeZeeuw and Dudek 2019); (Prarthana et al. 2025); (Duijnhoven et al. 2020).

Interpretation: The lack of a statistically significant between-group difference in PEDI-2 supports the view that functional independence in CP emerges from a constellation of factors, including age/development, access to environment and services, and family support, rather than orthosis type alone. Nonetheless, the broader distribution in the jointed-AFO group suggests that mobility flexibility afforded by articulation may support more consistent functional performance for some children, echoing prior findings that mobility outcomes can be variably affected by AFO design features (Žižienė et al. 2021); (Rogati, Caravaggi, and Leardini 2022); (DeZeeuw and Dudek 2019).

4) Comfort and Satisfaction (QUEST)

Table 4. QUEST

Types of AFO	N	Mean Rank	Sum of Ranks
Jointed AFO	23	23,87	549
Rigid AFO	17	15,94	271
Total	40		

Source: Personal data (2025)

The jointed AFO group demonstrated significantly higher comfort scores than the rigid AFO group, with a moderate effect size (approximately r = 0.34). Distributional analysis showed extreme skewness and kurtosis in the rigid AFO group (predominantly low comfort with few high-satisfaction cases), whereas the jointed AFO group displayed broader, more balanced satisfaction levels. This pattern reinforces the established notion that comfort and wearability strongly influence user acceptance and adherence to orthotic devices (H. Nazha et al. 2023); (Das, Mohapatra, and Lenka 2018); (Swinnen et al. 2018); (Thitithunwarat et al. 2023); (Duijnhoven et al. 2020)).

Interpretation: Comfort appears to be strongly affected by AFO design, with jointed AFOs enabling more natural ankle motion and potentially reducing discomfort related to mechanical restriction. The observed comfort advantage for jointed AFOs aligns with the literature emphasizing comfort, wearability, and ease of use as determinants of adherence and real-world effectiveness (H. M. Nazha et al. 2023); (Das, Mohapatra, and Lenka 2018); (Swinnen et al. 2018); (Thitithunwarat et al. 2023)).

5) Regression analyses

Predicting independence: Age emerged as the strongest predictor of independence. AFO type showed only a weak effect on PEDI-2 independence scores, suggesting that developmental maturation remains a primary driver of functional independence, with orthotic design contributing modestly relative to age and experience. This finding is compatible with developmental trajectories noted in CP rehabilitation literature, where maturation and environmental interaction play substantial roles in independence outcomes.

Predicting comfort: AFO type was the strongest predictor of comfort, with rigid AFOs associated with lower satisfaction. This supports the distributional findings and converges with prior work indicating that design constraints significantly shape perceived usability and satisfaction, which in turn influence wear-time and outcomes.

The regression results reinforce a dual-pronged clinical message: (a) age/development is a dominant driver of independence, and (b) AFO design strongly influences comfort, which is a key mediator of adherence and, therefore, of potential functional gains. These patterns are consistent with integrated models of orthotic efficacy that emphasize balancing mechanical control with user-centered design to optimize real-world outcomes.

6) Integrated outcome analysis

An integrated outcome analysis suggests that different types of ankle–foot orthoses (AFOs) provide distinct advantages across key domains. In terms of function, rigid AFOs offer superior support for functional stability and effective stance control, making them particularly beneficial for children who require enhanced postural alignment during gait. Regarding independence, jointed AFOs introduce greater mobility adaptability, which may facilitate improved participation in daily activities for some children, depending on their functional capacity. From a comfort perspective, jointed AFOs are generally associated with higher levels of user-centered comfort and satisfaction. This increased comfort may play a critical role in promoting adherence and supporting sustained, long-term use of the orthosis.

This multidimensional pattern aligns with the growing consensus that orthotic success in CP requires balancing biomechanical efficacy with user-centered outcomes, including comfort and wear time, to achieve functional independence in daily life (H. Nazha et al. 2023); (Das, Mohapatra, and Lenka 2018); (Žižienė et al. 2021); (Bjornson et al. 2023).

7) Clinical decision framework

Table 5. Proposed algorithm

1	GMFCS III–V	Prefer rigid AFO when stability and controlled knee/ankle alignment are prioritized to support a safer stance and push-off.
2	GMFCS I–II	Consider a jointed AFO to maximize mobility and adaptability, provided comfort is adequate and wear-time is acceptable.
3	Low QUEST scores	Reassess fit, adjust alignment, or redesign the orthosis to improve comfort and adherence.

Source: Personal data (2025)

If independence is moderate-to-high: Prioritize joint AFO to favor mobility and functional participation, while monitoring comfort and wear-time. The algorithm reflects the observed trade-off between biomechanical control (favoring rigidity) and user-centered outcomes (favoring jointed design with greater comfort), consistent with contemporary rehabilitation frameworks that integrate functional outcomes with adherence determinants to optimize CP orthotic care (H. Nazha et al. 2023); (Ricardo et al. 2021); (Bjornson et al. 2023); (Buckon et al. 2001)); (Harlaar et al, 2010).

Notes on limitations and replication considerations

Convenience sampling and the cross-sectional design limit causal inferences about AFO effects on independence and comfort; longitudinal data would enable stronger causal conclusions and trajectory analyses across GMFCS levels (DeZeeuw and Dudek 2019); (Prarthana et al. 2025). The distributions observed for GMFCS-related outcomes and QUEST scores underscore the importance of reporting full distributional statistics (skewness/kurtosis) along with central tendency to capture heterogeneity in CP

orthotic responses (Harlaar et al, 2010). Future work should stratify results by GMFCS bands and incorporate wear-time data to enhance interpretability and translational value (Majewska et al. 2020); (Žižienė et al. 2021).

The results support a nuanced, multi-domain evaluation of AFOs in CP, showing that rigid AFOs may yield superior gross motor function in some contexts, while jointed AFOs tend to improve comfort and, in turn, adherence and perceived mobility. An integrated clinical decision framework that weighs functional goals against patient-centered factors is justified by the observed patterns and aligns with current CP orthotics literature advocating balanced, personalized prescriptions (Gordo et al. 2019); (H. M. Nazha et al. 2023); (Ricardo et al. 2021); (Žižienė et al. 2021); (Bjornson et al. 2023); (Buckon et al. 2001).



***Figure 1**. Differences (1) Rigid AFO and (2) Jointed AFO*

Discussion

While the observed trends suggest differential advantages between rigid and jointed AFO designs, these findings should be interpreted cautiously in light of several methodological considerations (H. Nazha et al. 2023); (Gordo et al. 2019); (Miccinilli et al. 2024). First, the relatively small sample size may have limited statistical power to detect subtle differences, particularly for independence outcomes, where only small effect sizes were observed (Miccinilli et al. 2024); (Goihl et al. 2021). Consequently, the absence of statistically significant differences in PEDI-2 scores should not be interpreted as definitive evidence of equivalence between orthotic designs (Goihl et al. 2021); (Gordo et al. 2019); (Ricardo et al. 2021).

Second, the observational nature of the study precludes causal inference. Participants were not randomly allocated to rigid or jointed AFO groups, and orthotic prescription likely reflected underlying clinical characteristics, such as gait pattern severity, residual ankle mobility, muscle strength, spasticity level, or clinician preference (Majewska et al. 2020); (Miccinilli et al. 2024). Children prescribed rigid AFOs may have presented with greater biomechanical instability, whereas those receiving jointed AFOs may have retained greater functional ankle motion, potentially influencing outcomes independently of the orthosis design itself (Majewska et al. 2020); (MacFarlane, Hing, and Orr 2020); (Gordo et al. 2019). Therefore, some of the observed differences may reflect baseline clinical characteristics rather than the direct effects of the devices.

Third, alternative explanations may account for the comfort advantage observed among users of jointed AFOs. Greater comfort may not solely arise from the articulated design but could also be influenced by factors such as orthosis fit, fabrication quality, footwear compatibility, duration of use, previous orthotic experience, or caregiver perceptions. Similarly, independence outcomes are likely influenced by broader contextual factors, including rehabilitation intensity, environmental accessibility, family support, and opportunities for participation, all of which were beyond the scope of the present analysis (Miccinilli et al. 2024); (Goihl et al. 2021); (Waterval et al. 2023).

These considerations highlight the complexity of evaluating orthotic effectiveness in children with CP. Rather than indicating superiority of one design over another, the findings may reflect the need to balance biomechanical control with user experience according to individual clinical presentations. Future prospective studies with larger samples, longitudinal follow-up, and randomized or matched-group designs are needed to clarify the extent to which observed differences are attributable to AFO design itself and to identify patient characteristics associated with optimal orthotic selection (Goihl et al. 2021); (Gordo et al. 2019); (Miccinilli et al. 2024).

Conclusion and Recommendation

The findings of this study suggest that orthotic prescription in children with CP should consider multiple domains, including functional ability, independence, and comfort, rather than relying solely on biomechanical outcomes. Based on the observed patterns, we propose a preliminary clinical decision framework that may help clinicians conceptualize the trade-offs between mechanical stability and user-centered outcomes when selecting between rigid and jointed AFO designs. However, this framework should be regarded as a conceptual model derived from the interpretation of the present findings and existing literature rather than a validated clinical decision tool. Consequently, its application in clinical practice should be undertaken cautiously and in conjunction with comprehensive patient assessment, clinical expertise, and individual goal setting.

Implications for Research

The proposed framework represents an initial step toward a more integrated approach to AFO prescription in children with CP. Future studies should prospectively evaluate and validate this model across diverse CP populations and clinical settings (Miccinilli et al. 2024); (Goihl et al. 2021); (Gordo et al. 2019). Such validation may include longitudinal cohort studies, randomized comparative trials, or expert consensus approaches to determine whether framework-guided prescription improves functional outcomes, adherence, comfort, and participation (Miccinilli et al. 2024); (Goihl et al. 2021); (Waterval et al. 2023). In addition, future research should continue to document multidimensional outcomes and relevant contextual factors, including GMFCS level, wear-time, caregiver support, and environmental influences, to refine and strengthen the framework's clinical utility (Miccinilli et al. 2024); (Goihl et al. 2021); (Waterval et al. 2023).

AFOs remain an important component of CP rehabilitation, with rigid designs appearing to provide greater mechanical stability and functional support, whereas jointed designs may offer advantages in comfort and wearability (Majewska et al. 2020); (MacFarlane, Hing, and Orr 2020); Altschuck et al., 2019). Given the multifactorial nature of independence and participation, orthotic prescription should be individualized and aligned with patient-specific goals and clinical characteristics (Goihl et al. 2021); (Miccinilli et al. 2024). The clinical decision framework proposed in this study should be considered a preliminary conceptual model that requires prospective validation before it can be

recommended for routine clinical implementation (Goihl et al. 2021); (Gordo et al. 2019); (Miccinilli et al. 2024). Although the proposed framework is informed by the present findings and supported by existing literature, it has not been directly validated and should therefore be interpreted as a hypothesis-generating conceptual model rather than a definitive clinical decision algorithm.

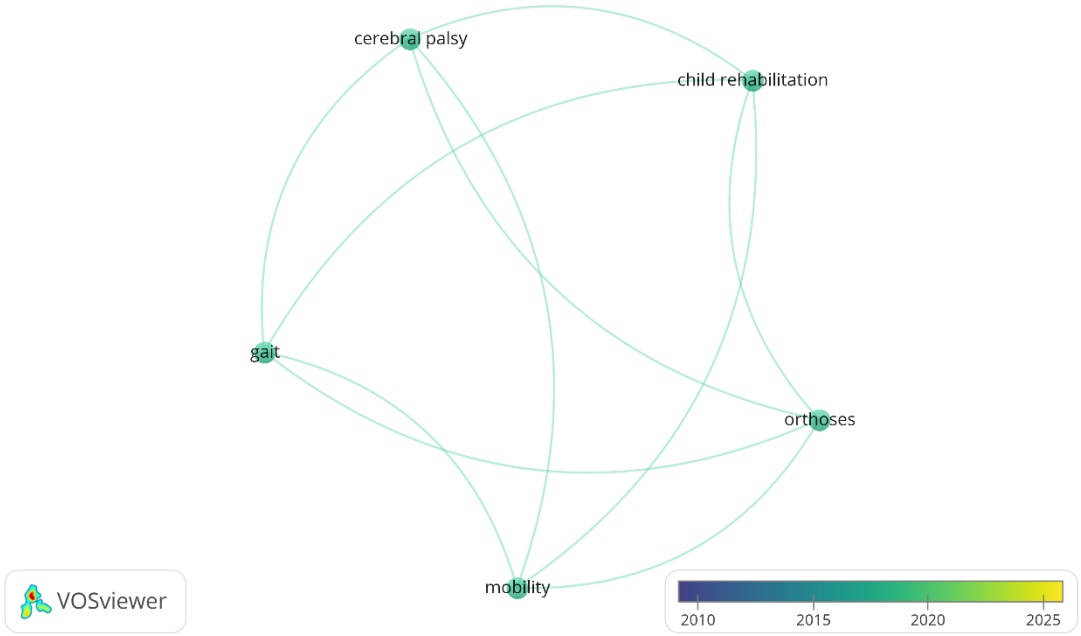


***Figure 2**. Vosviewer visualization with correlation strength*

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