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The Impact of Multisensory Integration Approach in Enhancing the Quality of Daily life Activities for children with Cerebral Palsy

Dr. Marwa Hamdy Mohamed Elsaid Nasr

Assistant Professor at Curriculum & Instruction Department Faculty of Education, Sultan Qaboos University, sultanate of Oman.

Abstract:

This study investigates the potential advantages of employing a multisensory integration approach in motor learning and performance. By repeatedly stimulating various sensory systems, such as combining visual and auditory cues, the brain may effectively process and learn from relevant sensory stimuli. The research focuses on examining the control and coordination of reaching and grasping a tennis ball in six children with cerebral palsy (CP) under two conditions: a non-sound ball (NS) condition and a pure tone sound (PTS) ball condition, from their seated positions. Quantitative data on upper limb movement were collected using a 3D Qualisys motion capture system. Preliminary findings suggest that the audio-visual condition (pure tone sound ball) demonstrated a more synchronized movement pattern compared to the visual condition (non-sound ball). This suggests that the addition of sound cues to the ball may have facilitated the integration of multiple sensory inputs. Consequently, children were able to simultaneously utilize visual and auditory information to guide their hand movements. This integration of sensory cues likely promoted increased attention to relevant sensory inputs, ultimately resulting in improved motor performance.

Keywords: (Multisensory Integration, Quality of Daily life Activities, Cerebral Palsy)

Introduction:

In essence, the integration of multisensory approaches into daily life activities holds tremendous potential for optimizing the functional abilities and overall quality of life for children with movement difficulties especially children with cerebral palsy (CP) (Marwa et al.2022). By capitalizing on the brain's innate capacity to integrate sensory inputs, therapists and caregivers can create tailored interventions that address the multifaceted needs of these individuals, empowering them to participate more fully in the world around them.

The topic of the current study arises from the authors' keen interest in understanding the movement patterns of children, particularly those with movement impairments such as cerebral palsy (CP), and how these children coordinate and control their upper limbs during daily activities. Children with (CP) often encounter significant challenges in performing daily life activities that many of us take for granted (Steenbergen et al.,2006, Rosenbaum et al., 2004). Simple tasks, such as dressing, eating, and grooming, can become formidable hurdles due to motor impairments and sensory processing difficulties (Marwa et al.2022). However, the integration of multisensory approaches into therapeutic interventions offers a promising pathway towards enhancing these essential daily life activities for children with CP.

For children with CP, mastering such movements can prove challenging. Despite difficulties in handling objects, moving, observing movement, and exploration, these children engage in a crucial learning process vital for their overall development (Abdel Malak et al.,2020). Utilizing our arms in both unimanual and bimanual actions, we accomplish a myriad of tasks vital for feeding, caring, communication, and object manipulation. While the act of reaching for an object may seem simple, research across psychophysics, physiology, and neurology suggests that successful execution requires the brain to integrate information about the object's spatial position (typically visual) and the hand's position (proprioceptive and visual) (Engel-Yeger et al.,2009; Astill & Utley, 2009).

Most environmental events involve multiple sensory systems to enhance perception quality. Our senses possess the remarkable ability to interpret complex spatial and temporal information and integrate it into a meaningful representation of our surroundings (Stein et al. 2008). Numerous studies underscore the brain's capacity to utilize the integration of information from different sensory modalities to improve event detection, localization, and response (Giard et al.2009, Mctntyre et al.2010, Steenbergen et al. 2006). The superior colliculus (SC), a midbrain structure receiving visual, auditory, and somatosensory inputs, is pivotal in multisensory integration (Stein et al.2008). Multisensory integration has been observed to influence behavior across various populations, including animals, adults, and children with and without movement difficulties. Combining multiple stimuli, especially when presented congruently, enhances human behavior, particularly in tasks such as pointing, reaching, and grasping objects (Giard et al, 1999; Astill et al.2010). By simultaneously presenting multiple stimuli, participants demonstrate improved environmental perception and manual direction identification, especially in response to novel sounds.

Beyond basic self-care tasks, multisensory approaches can also enrich teaching, leisure and recreational activities for children. The human senses serve as natural conduits, transmitting information to the brain for processing and comprehension through sight, hearing, touch, smell, and taste (Itagi et al.2019). These senses play a crucial role in understanding presented information and recalling it when needed for appropriate action. Recognizing the diversity of individual learning styles, educators in educational institutions should embrace the Multi-Sensory Approach to effectively convey teaching content in the classroom, catering to each learner's unique needs and fostering academic excellence. By addressing the auditory, visual, and kinesthetic dimensions of learning, the "Itagi's Model of Multi-Sensory Approach" endeavors to unlock students' full academic potential and promote educational success (Itagi et al.2019).

In addition to the above, Zhang et al. (2021) validated the efficacy of multisensory exercises in enhancing balance among individuals with balance disorders. Engagement in multisensory exercises has been shown to reduce the risk of falls and reinforce confidence levels, thereby enhancing overall quality of life. However, further investigation is warranted to determine the most effective strategies for implementing multisensory exercises and to delve into the neural and molecular mechanisms underlying the improvement in balance attributed to such exercises.

Multisensory exercises encompass activities that concurrently stimulate at least two sensory modalities from various sensory systems, including visual, auditory, tactile, vestibular, and somatosensory systems, among others (Stein et al.2008). These exercises hold potential for improving balance by enhancing the central nervous system's (CNS) capacity to process and integrate sensory inputs, thereby facilitating compensation for deficient sensory inputs (Zahang et al.2021). This process likely involves the establishment of improved connectivity among interconnected neural circuits regulated by the CNS (Pranjic et al.2023, La Merre et al.2018).

Comparatively, both multisensory exercises and vestibular rehabilitation aim to promote balance by modulating CNS plasticity, while physical exercises primarily target enhancing physical function (Konard et al.2024). In terms of sensory inputs, multisensory exercises offer simultaneous stimulation of multiple sensory systems (Barry et al.2020; Stein et al.2008), whereas vestibular rehabilitation predominantly focuses on stimulating the unisensory system, such as vision or somatosensory sensation. While multisensory exercises aid in facilitating CNS compensation for multisensory afferents, vestibular rehabilitation primarily targets patients with vestibular dysfunction to promote their vestibular compensation (Barry et al.2020; Stein et al.2008; Giard et al.1999; Zhang et al.2021).

Numerous brain regions play crucial roles in processing multisensory information, including the superior colliculus and the posterior parietal cortex (Talsma et al.2010; Allison et al.2018). Findings suggest that engaging in multisensory exercises can lead to an increase in brain volume, enhancing the brain's ability to process multisensory information and maintain balance (Lam et al.2018). Achieving balance necessitates multisensory integration (MSI) (Hu et al.1994), wherein the nervous system combines inputs from multiple senses to form a stable and coherent perception of the environment, thus eliciting appropriate bodily responses (Cruz et al., 2011). When sensory inputs from the environment are diminished, other sensory inputs compensate for the reduction (La Merre et al.2018; Barry et al.2020).

Furthermore, multisensory integration can be incorporated into feeding and mealtime routines for children with CP. By presenting food in visually appealing ways, incorporating diverse textures and flavors, and providing auditory cues such as music or verbal prompts, therapists can enhance the sensory experience of eating and encourage exploration of different food items (Anaby et al., 2013). This not only promotes nutritional intake but also cultivates positive associations with mealtimes, addressing potential feeding aversions commonly observed in children with CP (Marwa et al., 2022; Abdel Malak et al., 2020).

Therefore, this study aims to enhance the quality of daily life activities for children with cerebral palsy using the multi-sensory integration approach by achieving the following duties:

1) Examining control and coordination of upper limb movements in children with cerebral palsy,

2) Investigating the effect of the use of integrated stimuli on control and coordination in this population. Specifically, the research focuses on examining unimanual prehension tasks in a sample of children with CP. In addition to previous, Piech et al. (2004) research directions include investigating how multisensory interactions contribute to learning and development in children Moreover, preliminary findings suggest that exposure to bimodal stimuli enhances motor skills, spatial awareness, and coordination, holding promise for improving movement production and motor development in this population (Tjernstorm et al.2016; Whitney et al.,2016).

According to Jeannerod's model of prehension delineates two distinct components controlled independently: transport, which involves moving the hand towards an object, and grasp, which encompasses shaping the hand to accommodate object properties. Understanding the intricate interplay between these components is essential for elucidating the complexities of upper limb movements in children with CP. Therefore, the current research focuses on examining unimanual prehension tasks in a sample of children with CP.

Methodology:

Participants:

Six children (2 females and 4 males) aged 12-16 years (M =14 years, SD = ± 1) who met the clinical criteria for CP were involved in the study. Primary and Secondary schools were contacted to nominate volunteers for the present studies. CP participants were identified if they were previously diagnosed with any type of CP acquired before 1 year of age, able to ambulate either independently or with assistive mobility devices and able to voluntary move their upper limbs. Participants were excluded if they suffered from any visual or hearing impairment that would interfere with carrying out the testing, uncountable seizures, severe cognitive deficits that would impair their ability to follow simple verbal commands or suffered from severe postural abnormalities limiting their ability to maintain themselves in a seated position.

All parents/guardians signed the consent forms and children gave their willingness to take part by signing the consent forms before taking part in the study. Approval by the local research ethical committee of the faculty of biological sciences at the University of Leeds, and the South Yorkshire Ethics Committee (NHS) was performed prior to recruitment of participants.

Task:

Participants reached and grasped a tennis ball unimanually in two different experimental conditions and each task was completed using their dominant and non-dominant hand. These tasks were 1) non-sound ball, 2) ball with pure tone sound (PTS). Participants were asked to move their arm 20 cm to unimanually reach and grasp a stationary tennis ball using their dominant and non-dominant arm in response to a stimulus. A block of 6 trials was completed with each limb (arm) consisting of 3 non-sound trials, 3 pure-tone sound (PTS) trials. In total, each participant performed 12 trials (6 trials with each arm). Participants were instructed to reach and grasp the ball/s unimanually as naturally as possible (preferred speed) when the stimulus was heard. For the non-sound ball, participants were instructed to reach and grasp the tennis ball/s following the "go" signal from the experimenter. At the end of each trial participants were required to place both hands back on the starting position. A random time interval of 2-5s preceded the next trial. A 3D movement trajectory of the reaching component and the grasping component were calculated (Giakas et al.2000).

Kinematic Analysis:

3D Qualysis motion capture system was used to collect quantitative data of the upper limp in children with and without cerebral palsy. Five Proreflex (MCU 240, Qualisys, Gothenburg, Sweden) motion capture unit (MCU) cameras were used to capture the motion of the movement. Each MCU emits light from 250 infrared LEDs mounted around the lens. The MCU receives reflected light from low mass markers to capture limb movements at 240 Hz. All five cameras are positioned in a semicircular fashion to cover the full movement of participants` upper limb. All five cameras were positioned at 1.4 m measured from the edge of the reaction timer board. The Pro-reflex camera system was configured to allow the calibration of a movement volume approximately 2 m long X 1.5 m wide X 1.5 m high. Calibration was taken using the standard 751.2mm wand and coordinate frame for 60 seconds at a sampling frequency of 240 Hz. Calibration was believed to be sufficiently accurate if the standard deviation of the reconstructed wand length was less than 1 mm in the x, y, and z directions. From this scale, markers placed on the participants` joints could be located and measurements could then be computed and compared. The calibration wand was used as described above by moving it through the measurement space. Before each testing session, the volume of space where the movement took place was calibrated with accuracy below 1 mm.

Reaching and grasping analysis:

Participant's' Movement Time (MT), duration between the initiation and completion of reach measured in mms, and Peak velocity (PV), the maximum velocity attained by the wrist during the reach, occurring at its highest point within the resultant value, expressed in meters per second (m/s) were captured using the kinematic analysis. Regarding the grasp component, spatial parameters include Maximum Grip Aperture (MGA), defined as the maximum distance between the thumb and index digit, measured in centimeters. Additionally, the placement of the maximum aperture as a percentage of the total reach time (%MGA) is of interest (Astill & Utley, 2008).

Findings

Non-Sound Ball Analysis:

In visual condition 1 (non-sound ball), participants with spastic diplegia exhibited a velocity profile characterized by one acceleration and one deceleration phase, with the former typically longer than the latter. Notably, the non-dominant wrist of CP3 spent approximately 45% of the total movement time accelerating toward the ball. CP4 demonstrated partially equal phases, accounting for 50% to 52% of the total movement time. However, CP3 exhibited a complex velocity profile with multiple acceleration and deceleration phases (figure 1)

Peak velocities (PV) ranged between 740 m/s and 1.62 m/s for the dominant wrist, and between 568 m/s and 1.63 m/s for the non-dominant wrist, respectively. Meanwhile, movement times varied from 515 MS to 703 MS for the dominant wrist, and from 622 MS to 1.34 s for the non-dominant wrist, respectively. Across participants with spastic diplegia, the dominant and non-dominant wrists displayed moderate temporal synchrony in this condition, with average correlations between wrists reaching 0.66, indicating a moderate level of coupling between the limbs.

Figure (1). Mean wrist velocities for spastic diplegia in condition 1(NS=non-sound ball), RW, dominant wrist; LW, non-dominant wrist.

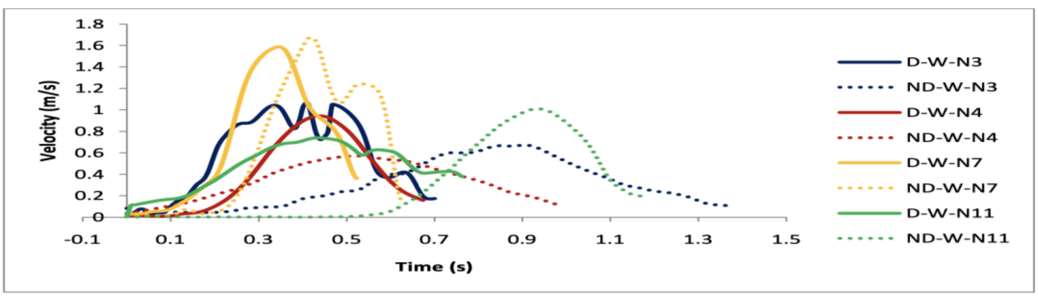
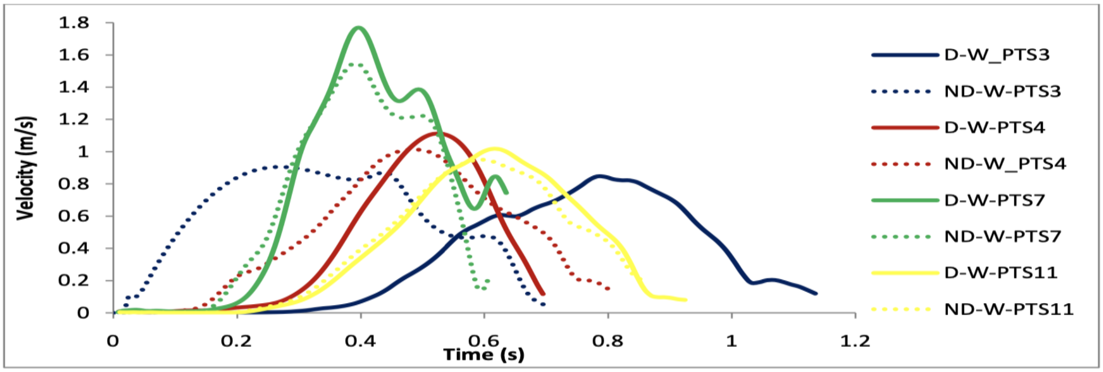


Figure (2) displays the velocity profile observed in the hemiplegic group. This profile is characterized by longer acceleration phases compared to deceleration phases. Peak velocities (PV) ranged from 0.160 m/s to 1.06 m/s for the dominant wrist, and from 0.526 m/s to 0.746 m/s for the non-dominant wrist, respectively. Movement times (MTs) varied between 591 MS and 3.26 s for the dominant wrist, and between 771 MS and 1.68 s for the non-dominant wrist. In this condition, the dominant and non-dominant wrists of the hemiplegic group did not exhibit temporal synchrony. Notably, the dominant wrist of CP4 displayed significantly reduced peak velocities. The average correlation between wrists was 0.15, indicating a very low degree of limb coupling.

Figure (2). Mean wrist velocities for hemiplegia in condition 1(NS=non-sound ball), RW, dominant wrist; LW, non-dominant wrist

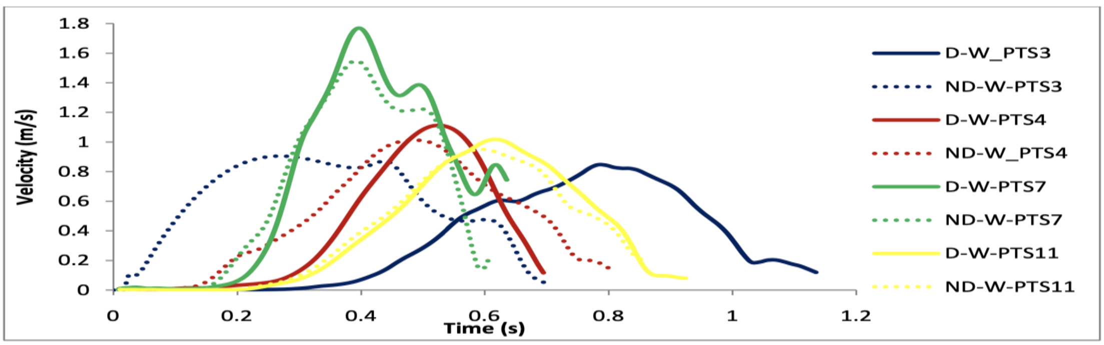


Pure-tone Sound Ball Analysis:

In the spastic group, wrist profiles generally exhibited longer acceleration phases, except for the non-dominant wrist of CP3, which accounted for 38% of the total movement time, as depicted in Figure (3) under audio-visual condition 2 (pure-tone sound ball), participants displayed a more synchronized movement pattern compared to visual condition 1 (non-sound ball). This synchronization was accompanied by shorter movement times, ranging between 627 MS and 1.12 s for the dominant wrist, and between 590 MS and 844 MS for the non-dominant wrist. Furthermore, higher peak velocities (PV) were observed, reaching 0.485 m/s to 1.75 m/s for the dominant wrist, and 0.905 m/s to 1.52 m/s for the non-dominant wrist, respectively. Notably, participants CP3 and CP2 demonstrated temporal synchrony in this condition, with average correlations between wrists of 0.61, indicating a moderate level of limb coupling.

In the hemiplegic group, a partial longer acceleration movement profile was observed, except for the non-dominant wrist of CP6, which accounted for 38% of the total movement time. Participants in condition 2 exhibited synchronized movement patterns, with movement times ranging between 726 MS and 1.58 s for the dominant wrist, and between 652 MS and 1.05 s for the non-dominant wrist. Peak velocities varied between 0.651 m/s and 0.889 m/s for the dominant wrist, and between 0.541 m/s and 1.32 m/s for the non-dominant wrist. Participants CP5 and CP6 demonstrated temporal synchrony in this condition, with correlations ranging between 0.87 and 0.93, suggesting a high to very high degree of limb coupling."

Figure (3) Mean wrist velocities for spastic diplegia in condition 2 (PTS = pure-tone sound ball), RW, dominant wrist; LW, non-dominant wrist.

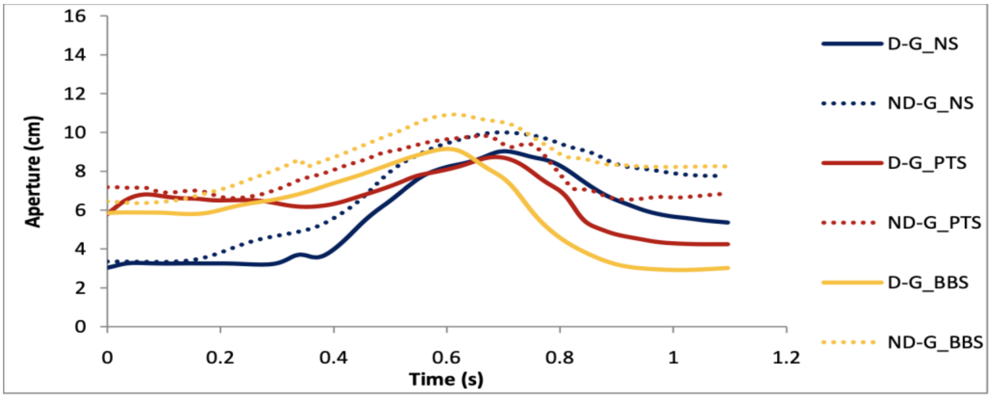


Aperture profile for the CP:

Figure (4) show aperture profiles for the CP children. The presented figures show aperture profiles for the CP group, in two experimental conditions: non-sound ball (NS), pure-tone sound ball.

The maximum aperture for the non-dominant and dominant hands of the CP group ranged between 9.61 and 9.92 cm in condition 1(non-sound ball), and between 9.75 and 9.83 in condition 2 (pure-tone sound ball). Maximum aperture was variably reached between participants and conditions between ~ 200-800 ms. Figure (4) shows grip differences in a child with spastic hemiplegia (CP5) reaching ~ 400-800. No differences in maximum grip were found between conditions.

Figure (4). Aperture profile for a spastic hemiplegia participant CP5 in unimanual prehension. D-G_NS is a mean representative profile of CP participant`s dominant grip in non-sound condition; PTS, pure-tone sound condition. ND-G = non-dominant grip.



Discussion:

The primary objective of this study was to examine the kinematic aspects of unimanual prehension movements in children with cerebral palsy (CP) while employing bimodal stimuli (pure-tone sound ball) as compared to unimodal stimuli (non-sound ball). An investigation revealed the presence of double and multiple peaked velocity profiles among participants. The variability in peak velocities had a significant impact on both Movement Time (MT) and the Peak Velocity (PV). While most CP children exhibited velocity profiles characterized by a single acceleration and deceleration phase, multiple profiles were particularly noticeable when reaching for the non-sound ball, using both their dominant and non-dominant hands.

Interestingly, the dual stimuli from the audio-visual condition (sound ball) demonstrated a more synchronized movement pattern compared to the visual condition (non-sound ball), as reported in previous findings in children with movement difficulties (Utley, Nasr, Astill, 2010), children with developmental coordination disorder (Coats, Britten, et al.2015; Pranjić etal.2023). This finding suggests that the addition of sound cues to the ball may have facilitated the integration of multiple sensory inputs (Giard, 1999), allowing children to utilize both visual and auditory information simultaneously to guide their hand movements (Barry et al.2020). This notion aligns with previous studies suggesting that combinations of sensory stimuli can enhance orientation to targets and facilitate the initiation of coordinated responses, such as directing gaze (King, 2010). This implies that leveraging multiple sensory modalities could offer promising avenues for improving motor coordination and task performance in children with CP (La Merre et al.2018; Talsma et al.2010).

Conclusion:

The previous findings, which emphasize the importance of manipulating task and environmental constraints and incorporating bimodal stimuli during therapeutic interventions for children with cerebral palsy (CP), directly align with the principles of multisensory integration. Multisensory integration involves combining inputs from different sensory modalities to enhance perception and behavior, and it plays a crucial role in improving the quality of daily life activities for individuals with CP.

By incorporating bimodal stimuli, such as combining visual and auditory cues, therapists can create a more enriched sensory environment that promotes efficient motor learning and skill acquisition. This integration of sensory inputs allows participants to become more sensitive to relevant information and increases their attention to task-related cues. As a result, children with CP may exhibit improved movement patterns and control strategies, as observed in the study's analysis of velocity profiles and kinematic landmarks.

Furthermore, the study highlights the effectiveness of bimanual movement in increasing functional abilities for children with CP. By engaging both upper limbs simultaneously, individuals can perform daily life activities more efficiently. This is particularly significant for children with CP as it promotes greater independence and participation in various tasks.Through repeated stimulation of multiple sensory systems via multisensory integration approach, the brain may learn from relevant sensory stimuli, allocate more attention to exercise-relevant sensory stimuli, and modulate bottom-up inputs to improve motor performance. Another potential mechanism is that multisensory integration could enhance the sensitivity of receptors in different sensory systems and improving its ability. Overall, promising preliminary findings of the impact of the multisensory integration approach in enhancing the quality of daily life activities for children with CP is seen across the study sample. By leveraging bimodal stimuli and manipulating task and environmental constraints, therapists can optimize motor function, promote skill acquisition, and ultimately improve the overall quality of life for children with CP. As research continues to advance in this field, the future holds promise for further innovations and refinements in multisensory interventions, offering hope for a brighter and more inclusive future for children with CP. Further exploration in this realm may yield valuable insights into optimizing rehabilitation strategies and enhancing functional outcomes for children with movement difficulties.

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