

Measuring Proprioception: A Cornerstone in Evaluation and Treatment of SPD

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Topics to be Covered

- Descriptions in the general literature
- Proprioception in Sensory Integration Theory
- Assessments utilized in research and practice
- The Comprehensive Observation of Proprioception (Blanche, Bodison, Chang, Reinoso, 2012)

Definitions: First Identified by Sherrington in 1906

- Afferent information from “proprioceptors”
- Muscle sense, postural equilibrium and joint stability
- Four submodalities of muscle sense
 - Posture
 - Passive movements
 - Active movements
 - Resistance to movement

Descriptions/Submodalities

- “Proprioception: the sum of kinesthesia and position sense
- Kinesthesia: awareness of joint movement (active and passive – lowest threshold for detecting joint rotation)
- Joint position sense: awareness of the static position
- Sense of resistance or heaviness
- Proprioception: summation of neuronal input from the joint capsules, ligaments, muscles, tendons and skin

(Ashton-Miller, Wotjys, Huston, & Fry-Welch, 2001; Grob, K. R.; Kuster, M. S.; Higgins, S. A.; Lloyd, D. G.; Ya ta, H., 2002; Lephart & Fu, 2000)

Functions Associated With Proprioception

- Motor programming
- Timing
- Calibration of spatial frame of reference
- Informing the CNS of the initial position of the peripheral system and the outcome of the motor command
- Joint stability
- Conscious estimation of muscle force
- Body scheme

(Bard, et al, 1995; Ferrel et al, 2004; La Rue, Baird, Fleury, Teasdale, Paillard, Forget, & Lamame, 1995; Laszlo, 1998)

Proprioceptive Dysfunctions in the General Literature

- Sports injuries (Beynon et al, 2002; Dover et al, 2003)
- Idiopathic Scoliosis (Kessen et al., 1992; Polak, 2013)
- Schizophrenia: Somatosensory deficits in weight and tactile discrimination (Chang and Leisenweger, 2005)
- Joint Hypermobility Syndrome (Ferrel, Tennant, Sturrock, Ashton, Creed, Brydson, & Rafferty, 2004)
- Clumsy children and Developmental Coordination Disorder (Ayres, 1972; Coleman, et al, 2001; Laszlo et al, 1993; Li et al., 2015; Sigmondsson et al, 1999;
- Autism Spectrum Disorder (Blanche et al., 2012; Mukhopadhyay, 2003; Roley et al., 2015; Slaperas et al, 2012)
- Asperger Syndrome (Weinert et al, 2001)
- Visual perception and oculomotor control (Ayres, 1972; Bedi et al., 2013; Shiyavi, 2016)

Proprioceptive Related Dysfunctions

- Disorders in body ownership: attributed to premotor cortex and parietal lobe damage (Giummarra et al., 2007)
- Mental health issues (i.e. depression)

Proprioception in Sensory Integration Theory

- Jean Ayres, PhD, OTR, FAOTA
- Motor performance
- Arousal modulation

THE PROBLEM: Therapists' Reports of their Observations Indicative of Inadequate Processing of Proprioceptive Information?

- Observation in natural play and environment
- Excess chewing
- Light touch on skin, postural praxis
- Art projects
- Can follow verbal instructions
- Running into things
- Ability to maintain spinal extension
- Grading movement
- Tripping, pushing, crashing
- Pressure on objects
- Weight bearing/shifting
- Low muscle, joint laxity, single limb stance
- Climbing
- Walking backwards
- Pushing carrying heavy objects
- Positive response to proprioceptive experiences
- Simon says game

CONT. THE PROBLEM: According to Therapists' Report: Unstructured Observations Indicative of Inadequate Processing of Proprioceptive Information?

- Seeking proprioception
- Body awareness
- Grading of movement and force
- Clumsiness
- Bumping into others and objects
- Muscle tone and muscle strength
- Joint integrity and co-contraction
- Postural control and weight bearing/shifting
- Pushing, hugging, leaning, safety awareness, inability to stay seated, tiptoeing, barging

Proprioceptive related dysfunctions (Blanche & Schaaf, 2001)

Hypo responses or poor discrimination of proprioception

- Breaks toys easily (clumsy)
- Low (functional) postural tone,
- May be accompanied by hypo- responsiveness to touch
- May seek large amounts of proprioception (as previous case),
- May tighten up or "fix"

Proprioceptive related dysfunctions

(Blanche & Schaaf, 2001)

Proprioception as a modulator (overuse)

- Presents sensory modulation deficits in other systems (tactile) - seeks large amounts of proprioceptive input to help modulate other sensory systems
- Bites, pushes, hits, scratches, bumps, hurls, bangs
- Behaviors may appear or labeled "aggressive"
- Moves fast, may appear clumsy)
- Likes chewy and hard foods) may exhibit self stimulatory behaviors (banging head, biting hands, etc.)

Anatomy

- Receptors
- Pathways
 - Dorsal Column Medial Lemniscal System
 - Spino-Cerebellar
- CNS levels of integration:
 - Spinal Cord: Muscle stiffness and joint stability
 - Cerebellum: Smoothing muscle action, repetitive motions, planning the next step, timing
 - Brain Stem: Postural control and muscle tone
 - Cortex: Programming, central commands

Proprioception and Motor Performance

- Motor programming
- Timing (depends on dispatch of the command to move and the afferent proprioceptive information at the onset of the actual movement)
- Informing the CNS of the initial position of the peripheral system and the outcome of the motor command
- Joint stability
- Conscious estimation of muscle force
- Multi-sensori comparison involving planning of a movement based on: feedback during a movement, past experience and the expected outcome of the movement

(Bard, et al. 1995; Ferrel et al. 2004; La Rue, Bard, Fleury, Teasdale, Pallard, Forget, & Lamarre, 1995; Luzzo, 1998; Proke & Gandevia, 2009)

Proprioception and Emotions

- Emotion regulation (Gellhorn, 1964; Wolfberg, 2000),
- Affective proprioception (Cole & Montero, 2007)
- Emotion-in-body (Longo, 2010)
(Affective processing of and responses to somatic stimuli)
- Modulation of the state of arousal (less studied)
- Proprioception as a motivator



Hypothesis about proprioceptive related dysfunctions

- Over use of Proprioception as a modulator
 - Not just seeking low intensity proprioceptive or kinesthetic input
 - Often referred for behavioral reasons
- Hypo responses or poor discrimination of proprioception
 - Clumsy, often exhibits low tone
 - Referred for motor related issues
 - May also seek low intensity proprioceptive input (leaning, fidgety, etc.)
- Both: intense seeker and motor difficulties

Proprioceptive Testing in the General Literature

Categories of Proprioceptive Tests

- Position Sense
 - Visual presentation
 - Active movement
 - Passive movement
- Movement Sense (movement threshold)
- Ipsilateral and contralateral measures
- Inter and intra sensory modalities (visuo-prop, vestibulo-prop, tactile-prop, prop-prop)

Approaches to Testing Joint Position Sense

- Joint position sense: matching of a defined index angle (flexion angle that must be reproduced by the subject) (Baynnon, Good, Risberg, 2002)
1. Visual analog of the limb
 2. Actively matching the index angle using opposite limb
 3. Actively matching the index angle using the same limb
 4. Passively matching the index angle using the opposite limb

Other Examples

- Balance systems
- Inter- and intra-modality matching device (Sigmundsson, Ingvaldsen, & Whiting, 1997)
 - Visual to prop
 - Visual/prop to prop
 - Prop to prop contralateral hand
 - Visual to prop memory

	Prop – Prop		Movement Sense	Visual/ Prop	Vestibular/ Prop	Tactile/ Prop
	Position Sense					
	Active/ Active	Passive/Active				
Not necessarily Ipsilateral nor contralateral			<ul style="list-style-type: none"> ○ Sequential finger touching ○ Finger to nose 	<ul style="list-style-type: none"> ○ Biodex ○ SWB ○ Test of sensory interaction for balance ○ Slow Ramp 	<ul style="list-style-type: none"> ○ Biodex ○ SWB ○ Test of sensory interaction for balance 	
Ipsilateral		<ul style="list-style-type: none"> ○ Kinesthesia ○ (SIPT) ○ Sigmundson ○ Kinesthetic Sensitivity Test (Laszlo) ○ Proprioceptometer ○ (Wucherley) 	Swanik et al	Sigmundson		MFP
Contralateral		Sigmundson				
Other	Muscle tone Grading Force Lafargue?					

“There was no correlation between the tests for kinaesthesia and JPS or between the different JPS tests. There was, however, a significant correlation between the tests for kinaesthesia ($r = 0.86$). We conclude therefore that a subject with a given result in one test will not automatically obtain a similar result in another test for proprioception. Since they describe different functional proprioceptive attributes, proprioceptive ability cannot be inferred from independent tests of either kinaesthesia or JPS”.

Grob, K. R.; Kuster, M. S.; Higgins, S. A.; Lloyd, D. G.; Yata, H. (2002). Lack of correlation between different measurements of proprioception in the knee. *The Journal of Bone and Joint Surgery-British Volume 84-B(4)*. pp.614-618

Parent Surveys

- Sensory Processing Measure – Home Form (Parham and Ecker, 2007)
- Sensory Profile (Dunn, 1999; 2015)

Unstructured Observations

- Muscle tone is decreased (not hypotonia)
- Decreased, slow, or absent weight bearing and weight shifting strategies
- Inappropriate grading of force
- Tiptoeing
- Tendency to push, pull, or hang
- Tendency to lean on others
- Need of visual input when copying simple body movements

Structured Clinical Observations

- Schilder's Arm Extension Test (Silver and Hagin, 1960)
- Slow ramp movements
- Finger to nose (Dunn, 1981)
- Sequential finger touching (Dunn, 1981)
- Alternating movements (Dunn, 1981)

→ Evaluation of Proprioception

- Lack of systematization
- Poor understanding of the relationship between proprioception and functional performance

Comprehensive Observation of Proprioception

Comprehensive Observation of Proprioception (COP) (Blanche, Bodison, Chang & Reinoso, 2012)

- Observational tool that identifies proprioceptive issues in children with developmental disabilities
- 15 to 30 minutes to complete while performing other skilled observations
- Has established construct and criterion validity as well as inter-rater reliability
- Responds to the need to systematize the clinician's observation of proprioception

Comprehensive Observations of Proprioception (COP)

- Content validity
- Inter-rater reliability
- Construct validity
- Criterion validity
- Preliminary factor analysis

Face and Content Validity

- Extensive literature review
- Expert analysis (9 therapists)
 - Five items eliminated
 - muscle tone is hypotonic
 - increased muscle tone
 - muscle tone is symmetrically distributed
 - muscles appear well delineated
 - inability to copy simple movements.

Area 1: Tone and Mobility

- Muscle tone is decreased (if muscle tone is increased, STOP now- do not complete form)
- Joint Hypermobility
- Lykert Scale:

1 NO SIGNS	2 SOMEWHAT	3 MODERATE	4 CONSIDERABLY	5 EXTREME
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Area 2: Skills

Adequate joint alignment or co-contraction (no fixing, no hanging on ligaments)
Efficient ankle strategies when negotiating uneven surfaces. Feet and hands actively respond to subtle shifts in posture.
Adequate weightbearing and weightshifting patterns in the extremities. No weightbearing on internal borders of feet or hands.
Postural control in sitting and standing is efficient for the task at hand. Is able to maintain his balance during activity.
Ability to motor plan feedback related activities. Is able to climb on to stationary equipment without difficulty. (WNL for his/her age)
Ability to motor plan feedforward related activities is WNL for his/her age. Is able to play with balls and other moving equipment.
Appropriate grading of force (during gross motor and fine motor tasks such as coloring, puzzles, etc.)

Area 3: Behaviors

Tiptoes or walks on toes
Tends to push others or objects
Tends to enjoy being pulled or hanging
Tends to lean on others or equipment, assume pro-gravity positions (seeking not related to postural control)
Is overly active (more than other children his/her age)
Is overly passive (more than other children his/her age)
Tends to crash, run, fall, jump, bump into others and objects

Interrater Reliability – Scale

raters	1	2	3	4
1		0.81	0.77	0.81
2			0.78	0.73
3				0.76
4				

Interrater Reliability by Areas

- Tone and mobility: .88
 - Skills: .96
 - Behavior: .35 (next step will require deleting items)
- TOTAL score (interclass correlation): .91

Construct Validity

- Does the COP discriminate children with and without proprioceptive problems?
 - 24 children (7 girls and 17 boys) between 2 and 8.11 years referred to occupational therapy
 - 20 children with non-identified issues
- Children with developmental disabilities (P group) had significantly higher scores than the children in the typical (NP) group (total score and all individual items (all p . .01) except Item 17 (overpassive; p = .12).

Criterion Validity: How does the COP Compare to other Measures of Proprioception? (Bodison, 2011)

- Body Awareness Items of the Sensory Processing Measure: Home Form (Parham & Ecker, 2007)
- Sensory Integration and Praxis Test:
 - Standing and Walking Balance
 - Kinesthesia (Ayres, 1989)

Criterion Validity: Method

- Chart review of 20 children identified with functional issues warranting OT services and who had been tested with the following measures:
 - Sensory Integration and Praxis scores: Kinesthesia (K) and Standing and Walking Balance (SWB)
 - Sensory Processing Measure – Home Form: items measuring proprioception
- Videotaped OT intervention session
Comprehensive Observations of Proprioception Scale
 - Pearson Correlation Analysis comparing individual COP scores with SIPT and SPM

Factors	COP Item	KIN (SIPT)	SWB (SIPT)	BOD (SPM)
1. Tone and joint alignment	2. Joint hypermobility	-.37		
	1. Decreased muscle tone	-.37		
	3. Poor joint alignment			
2. Behavioral manifestations	13. Pushing			
	16. Overactive			
	18. Crashing, falling, running			Item 49: .63*
				Item 53: .44*
3. Postural motor	14. Enjoyment when pulled			Item 53: .44*
	12. Tiptoeing			
	6. Decreased postural control			Item 55: .47*
	15. Tendency to lean		-.46*	Item 49: .47*
				Item 52: .48*
4. Motor planning	9. Inefficient grading of force	-.41*	-.41*	Item 53: .41*
	5. Inadequate weight bearing	-.38	-.39	
	4. Inefficient ankle strategies	-.37	-.49*	
	7. Decreased feedback planning	-.39	-.38	
	8. Decreased feed-forward planning		.36	
	17. Overpassive			

Preliminary Factor Analysis

- Review of 130 patient files with known developmental disabilities
- Results of the factor analysis revealed 4 factors: tone and joint alignment (Factor 1), behavioral manifestations (Factor 2), postural motor (Factor 3), and motor planning (Factor 4).

Construct	COP Item	EFA with Oblique Rotation			
Tone and Joint Alignment	Joint	0.822	0.079	-0.021	-0.104
	Muscle tone	0.774	-0.037	-0.086	0.154
	Co-contraction	0.674	0.018	0.164	0.093
Behavior Manifestation	Push	-0.013	0.752	0.094	0.125
	Active	-0.065	0.629	0.061	-0.305
	Crash	0.070	0.694	0.136	-0.064
	Pulls	0.067	0.671	-0.126	-0.038
	Tiptoe	-0.041	0.453	-0.161	0.288
Postural Motor	Postural	-0.045	-0.116	0.758	0.154
	Leans / Falls often	0.116	0.026	0.696	-0.078
	Grades force	-0.047	0.349	0.525	0.086
	Weight-bearing	0.440	-0.150	0.501	0.027
	Ankle strategies	0.296	0.052	0.404	0.214
Motor planning	Feedback	0.077	0.089	0.104	0.733
	Feedforward	0.097	0.132	0.159	0.530

COPS Factors 1 and 2

- Factor 1 loads with proprioceptive items targeting **muscle tone and proximal joint stability or co-contraction**. This factor focuses on what has been described as **spinal functions related to proprioception**.
- Factor 2 loads with items that are often viewed as **behavioral manifestations of proprioceptive seeking**. Its items correlate significantly with item #49 (*grasps object loosely*) and #53 (*pushes other children*) of the SPM, supporting the relationship between the therapist's and the parents' observations of behavioral difficulties related to proprioception.

COPS Factors 3 and 4

- Factor 3 loads with items that target components of adequate **postural control**. This factor represents postural and motor performance difficulties related to proprioceptive functioning.
- Factor 4 loads with items that represent **motor planning**. The items in this factor did not correlate significantly with any of the body awareness items of the SPM, suggesting that this factor is measuring aspects of proprioception that relate to motor planning. Future studies need to focus on correlating these items of the COP with the Postural Praxis and Sequencing Praxis test of the SIPT.

COP Scores in ASD and DD

- Total scores differentiate between children with DD and children with ASD
- Scores of children with ASD differed from children with DD in two factors:
 - Behavioral manifestations
 - Motor planning

Blanche, E.I., Reinoso, G., Chang, M., & Bodison, S. (2012). Evaluation of the comprehensive observations of proprioception scale (COP) on children with autism spectrum disorders and developmental disabilities. *American Journal of Occupational Therapy*, 66(5), 621-624

Method

- Retrospective group comparative design
- Participants:
 - 32 children diagnosed with ASD/no additional motor difficulties
 - 26 participants with DD excluding ASD
 - 28 matched control
- ANOVA for the three group comparison and applied a post hoc analysis with Tukey–Kramer method for pairwise comparison

Measures	Post Hoc comparison with Tukey's adjustment		
	ASD/DD	ASD/TYP	DD/TYP
Decreased muscle tone		*	*
Joint hypermobility		*	*
Poor joint alignment and co-contraction		*	*
Inefficient ankle strategies		*	*
Inadequate weightbearing/shifting		*	*
Decreased postural control		*	*
Decreased feedback	*	*	*
Decreased feedforward		*	*
Inadequate grading of force		*	*
Tiptoeing	*	*	-
Pushing others or objects	*	*	*
Enjoyment when being pulled		*	*
Tendency to lean on others		*	*
Over-active		*	*
Over-passive		*	*
Crashing, falling, running	*	*	*
COP total scores	*	*	*

Measures	Post Hoc comparison with Tukey's adjustment		
	ASD/DD	ASD/TYP	DD/TYP
Factor 1 Tone and Joint Alignment		*	*
Factor 2 Behavior Manifestation	*	*	*
Factor 3 Postural Motor		*	*
Factor 4 Motor planning	*	*	*

* indicates significant $p < .05$

So what? Guiding Intervention

- Overuse of proprioception – behavioral manifestations that lead to issues in participation (reason for referral)
- Motor disorders that lead to issues in participation

Intervention – Regulation of Attention, Emotion, and Behavior

- How it is utilized
- How it is evaluated
- Evidence from the literature

Intervention - Motor Performance

- How it is utilized
- How it is evaluated
- Evidence from the literature

Best Practice with Proprioceptive Deficits

1. We need to be able to describe the dysfunction
2. We need to come up with the most efficient way to assess the dysfunction
3. We need to continue developing intervention strategies that address the proprioceptive system in conjunction with the tactile, vestibular, and visual system.
4. We need to measure the effect of such intervention

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