Upper Limb Robotic Rehabilitation

국립재활원 김현경

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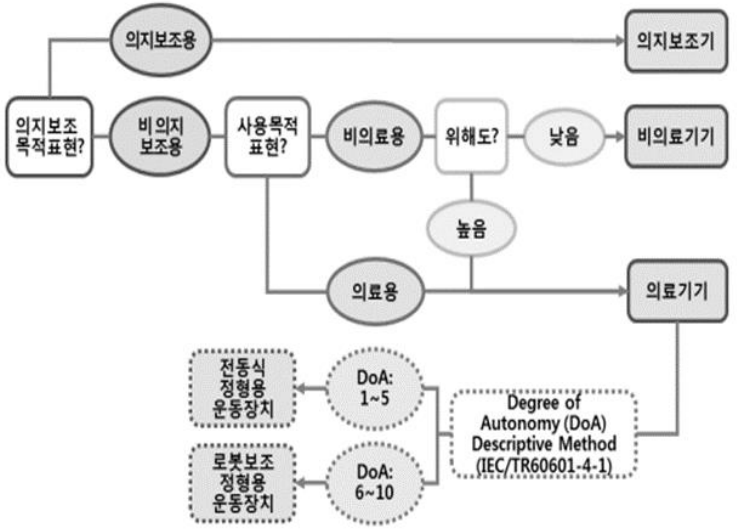
1. 재활로봇(Rehabilitation Robot): 정의

- **용어 정의 (넓은 의미)**
  - **재활로봇장치(robotic device): 재활에 사용되는 장치로** 로봇보다 자율성이나 구동할 수 있는 축수가 적은 경우를 포괄적으로 의미
  - **재활로봇**: **재활**(Rehabilitation, 운동기능을 향상시키는 치료), **평가**(Assessment, 장애의 중증도를 정량화, 정성화 평가), **보상**(Compensation, 신체적 구조를 지지하거나 신체적 기능을 보조 혹은 대체, 운동기능 향상을 포함하지 않음), **경감**(Alleviation, 환자가 갖는 장애로 인한 증상을 덜어주기 위한 처치)에 사용되는 로봇

(국제 전기 표준회의 기술보고서, IEC TR)

1. 재활로봇(Rehabilitation Robot): 정의

- **용어 정의 (좁은 의미)**
  - 로봇: 자율도를 갖는 기계장치로, 사용목적을 달성하기 위해 주변환경변화를 감지하여 입력된 프로그램에 따라 작동함
  - 의료용 재활로봇: 로봇보조 정형용 운동장치(3등급),
    근육의 재건 , 관절운동의 회복 등에
    사용되는 로봇 자동화 시스템 기기 (자율도 6~10)



(재활로봇 허가·심사 가이드라인,민원인 안내서: 식품의약품안전평가원, 2017/ 송원경,재활로봇중개연구 7년간의 경험과 시사점)

1. 재활로봇(Rehabilitation Robot): 사용 별 구분

- 일상생활 보조용 재활로봇
- 치료용 재활로봇

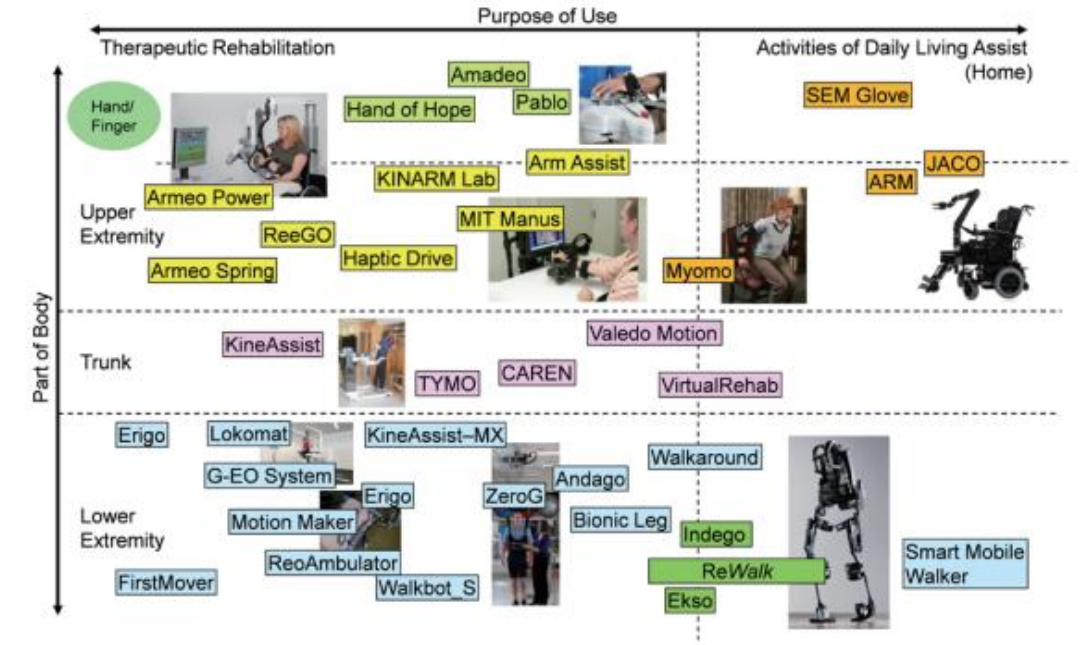


그림 1. 재활로봇의 분류. 수평은 용도, 수직은 신체 부위를 나타냄. 왼쪽은 치료재활, 오른쪽은 일상생활보조 용도임 [2].

(송원경, 재활로봇의 기술동향)

1. 상지재활로봇: 이번 발표에서는

- 상지에 적용되는 재활로봇장치(robotic device)
- 의료기기로 분류된 치료용 재활로봇장치

1. 상지재활로봇: 종류

1. Grounded Exoskeleton

- Full guidance
- Predefined motion performed by robot
- User's muscle effort not required
- Reducing the abnormal patterns of limb movement by controlling the participant's proximal joints properly

Armeo®Power
[Hocoma]

NX-A2
[Guangzhou YiKing Medical Equipment Industrial CO. LTD]

2. Grounded End-effector

- Patient-cooperative control
- Partial support to initiate and perform movement
- Haptic simulation for interaction environment

MIT-MANUS/Inmotion2
[Interactive Motion Technologies Inc.]

Amadeo
[Tyromotion]

3. Wearable Robot

- Free space
- Negligible interaction with robot
- Allows natural movement
- Requires user's muscle activity

mPower arm brace
[Myomo Inc.]

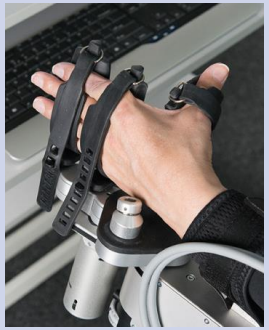
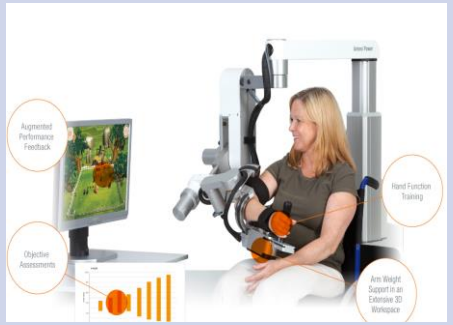
Soft robotic glove
[Harvard]

Gassert and Dietz. 2018

1. 상지재활로봇: 종류

Type	Device	Company	의료기기 등급	Shoulder	elbow	Forearm	wrist	Finger / hand	Target population
Exoskeleton	AmeoSpring+ ManovoSpring ArmeoSpring, Pediatric	Hocoma (Swizerland)	의료기기 2등급	v	v	v	v	v	Stroke, MS, SCI, TBI, CP
	ArmeoPower + ManovoPower		의료기기 3등급	v	v	v	v	v	Stoke, MS, SCI, TBI, CP
End -effector	InMotion ARM	Interactive Motion Technologies (USA)	의료기기 3등급	v	v				Stoke, TBI, CP
	InMotion WRIST					v	v		Stroke, SCI, MS,CP
	Amadeo	Tyromotion (Austria)	의료기기 3등급					v	Stroke, SCI, TBI, CP
Exoskeleton	Hand of Hope	Rehab-Robotics (China)	의료기기 3등급					v	Stroke, SCI
	Rapael	Neopect (Korea)	의료기기 2등급			v	v	v	Stroke ,CP

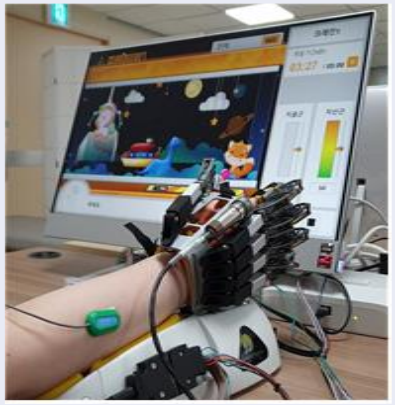
1. 상지재활로봇: 종류

Robot			
ArmeoPower + ManovoPower (hand module- grasping training)	3D motion	 	✓ 6자유도의 모터 구동 구조를 가지고 있어 보다 자연스러운 3차원 공간의 움직임 가능 - 로봇에 의해 팔이 움직임이는 수동동작방식 - 사용자의 의지에 의해 로봇 팔을 움직이는 동안 움직임이 지체되면 목표하는 위치로 상지를 움직여 주는 방식
ArmeoSpring + ManovoSpring **ArmeoSpring Pediatric**	3D motion	 	✓ 수동소자인 스프링만을 사용함 ✓ 팔에 착용해 환자 개개인의 근력에 맞춰 팔의 무게를 스프링을 통해 조정함으로써 상지의 능동적인 움직임을 유도하여 치료 진행

1. 상지재활로봇: 종류

Robot			
InMotion ARM (shoulder –elbow robot)	2D motion 치료 프로그램 : Active, Active-Assistive, Passive, Resistive Ex.로 구성 - shoulder and elbow joint movement		✓ 어깨-팔꿈치 움직임을 위주로 하는 운동으로 환자의 상태에 따라 적절한 빈도, 강도, 저항 및 움직임을 제공하여 치료 ✓ 환자의 관절가동범위, 협응능력, 근력, 움직임의 속도와 매끄러움 개선을 위해 적용
InMotion Wrist	2D motion 치료 프로그램 : Active, Active-Assistive, Passive, Resistive Ex.로 구성 -wrist flexion & extension -wrist pronation & supination		✓ 아래팔-손목 움직임을 위주로 하는 운동으로 환자의 상태에 따라 적절한 빈도, 강도, 저항 및 움직임을 제공하여 치료 진행

1. 상지재활로봇: 종류

Robot			
Amadeo	치료 프로그램 : CPM Motion, Assistive therapy, Motility (selective movement 유도)		✓ 환자의 손가락 끝부분에 로봇의 자석을 부착하고 로봇 손가락에 환자의 손가락을 고정한 후 로봇 프로그램에 따라 굽힘 및 신전의 반복적임 움직임을 제공하여 치료 진행
Hand of Hope	치료 프로그램 : CPM, EMG Biofeedback Training, Game으로 구성		✓ 표면 근전도 신호(sEMG)를 감지하기 위해 아래팔의 신전근과 굴곡근에 표면 센서를 부착하고 굽힘 및 신전의 반복적임 움직임을 제공하여 치료 진행.

1. 상지재활로봇: 훈련모드

훈련모드	특징
수동모드(Passive mode)	로봇이 수동 훈련에 대한 반복적인 추적 제어를 통해 환자가 미리 결정된 궤도를 따라 운동하도록 도움
능동모드(Active mode)	환자가 특정한 움직임을 가질 때, 재활로봇이 궤도 또는 보조력을 변화시킴
능동보조모드(Active assist mode)	"능동"모드의 일종. 환자는 사지를 움직이기 위한 어떠한 도움도 필요로 하지 않음. 임계값(Threshold) 이 특정 기준에 도달하면 로봇이 트리거(trigger) 됨.
능동저항모드(Active resist mode)	"능동" 모드의 일종. 환자가 사지를 움직일 때, 로봇은 운동을 더 고되게 만들도록 저항력을 제공함.

(의료기기 시험방법 정보자료집:하지로봇보조정형용 운동장치, 식품의약품안전평가원, **2020)**

2. 상지재활로봇: 효과

- **기전**
  - Kinematically consistent, reproducible & controlled movement
  - Task specific activity
  - Sufficient dosage, intensity, repetition
  - Early intervention
  - Multisensory and multimodality approach

    : by sensory feedback(visual, auditory, proprioception & haptic), cognitive engagement of robotic rehabilitation

→ 신경회복 촉진 (To facilitate neuroplastic process)

2. 상지재활로봇: 효과

- **Research for the neurologic population**
  - Adult (Stroke> SCI) > Childhood
  - Lower limb robotics> Upper limb robotics

	Total	Study design		Population*	Devices°	CE mark°	EE/Exo°
		RCT	Other	ST/TBI/MS/PD/SCI/CP			
	N. (%)	N. (%)	N. (%)	N.	N. (%)	N. (%)	N.
All studies	316	164 (52%)	153 (48%)	172/17/21/9/57/45	100	19 (19%)	47/53
Adults							
Upper limb	99 (31%)	52 (53%)	48 (47%)	85/2/7/1/8/0	44	11 (25%)	26/18
Walking and balance	164 (52%)	103 (63%)	61 (37%)	84/3/14/8/48/0	39	7 (18%)	10/29
Childhood							
Upper limb	22 (7%)	2 (9%)	20 (91%)	3/11/0/0/0/16	8	3 (38%)	7/1
Walking and balance	31 (10%)	7 (23%)	24 (77%)	0/1/0/0/1/29	17	3 (18%)	9/8

N.: number; Other: pilot: feasibility: observational studies; ST: stroke; TBI: traumatic brain injury; MS: multiple sclerosis; PD: Parkinson's disease; SCI: spinal cord injury; CP: cerebral palsy; EE: end-effector; Exo: exoskeleton.
*Studies may include more than one population (*i.e.*, stroke and TBI), and devices may be counted in both adult and childhood populations.

Candolfi et al, 2021: 검색 기간 November 2019~ January 2020

2. 상지재활로봇: 효과

- Robotic training alone
- Robotic training combined
  - with electrical stimulation
  - with transcranial direct current stimulation
  - with virtual reality
  - with botulinum toxin

2. 상지재활로봇: 효과

- UL Robotic training alone
  - Stroke Pt:
    1) repetitive task practice with robotic devices → class I level evidence in outpatient, Class IIA level evidence in inpatient (Miller EL, 2010)

2. 상지재활로봇: 효과

- UL Robotic training combined with electrical stimulation
  - Stroke Pt: improvement in motor function (FMA, Action Research Arm test, ROM..), robotic training + ES > robotic training alone.

- Robotic training combined with transcranial direct current stimulation
  - Stroke Pt: systematic review→ not result in greater improvement than robotic training alone(Hosess S, 2011).

2. 상지재활로봇 효과

- Robotic training combined with virtual reality
  - Stroke Pt: some evidence →effectiveness in motor function, ADL (Frisoli A, 2011)

- Robotic training combined with botulinum toxin
  - Minimal scientific support
  - Stroke, CP→ improvement of motor function and reduction of spasticity

2. 상지재활로봇 효과

- 대한 뇌신경재활학회(뇌졸중 재활진료지침, 2016)

  : 로봇을 포함한 기계 보조 상지 훈련은 장비사용이 가능하고 숙련된 인력이 있다면 상지 기능 향상을 위해 정선된 환자들에게 고식적 상지 훈련에 추가되어 시행되어야 한다 (권고수준 B/근거수준 1+)

2. 상지재활로봇: 뇌성마비

- **Chen, Howard(2016): Effects of robotic therapy on upper-extremity function in children with cerebral palsy: A systematic review**
  - 2013.7월까지의 연구 분석, 총 9개의 연구
  - InMotion2, hemiplegia 가 주됨(5개). Case series 위주(8개)

Study	Affiliation	Design	Sample size	Age range (mean age)	Children's type	Robot type (Contact or no–contact)	Intervention	Intervention dose	Quality score
[37]	MN	Randomize crossover design	6	5–18 (11.17)	2 hemi 4 quadri	CosmoBot (No–contact)	Robot v.s. Conventional	20mins × 2 days/week × 5 weeks	6/11
[33]	MIT	Single case	1	8.5	1 hemi	InMotion2 (Contact)	Robot + Botox	1 hr × 2 days/week × 8 weeks	8/11
[34]	MIT	Case series	12	4–12 (9.19)	12 hemi	InMotion2 (Contact)	Robot	1 hr × 2 days/week × 8 weeks	9/11
[38]	NJ	Case series	5	5–18 (10.20)	Not reported	NJIT–RAVR (Contact)	Robot + Virtual reality	1 hr × 3 days/week × 3 weeks	8/11
[39]	Italy	Case series	12	5–15 (11.67)	12 hemi	InMotion2 (Contact)	Robot	1 hr × 3 days/week × 6 weeks	7/11
[40]	MIT	Case series	13	5–12	13 hemi	InMotion2 (Contact)	Robot	1 hr × 2 days/week × 8 weeks	7/11
[36]	Italy	Case series	7	7–14 (10.00)	7 hemi	InMotion2 (Contact)	Robot	Immediate	5/11
[42]	NJ	Case series	2	7 & 10 (8.50)	2 hemi	NJIT–RAVR (Contact)	Robot + Virtual reality	1 hr × 3 days/week × 3 weeks	7/11
[41]	NJ	Case series	9	7–15 (10.10)	7 hemi 2 quadri	NJIT–RAVR (Contact)	Robot + Virtual reality	1 hr × 3 days/week × 3 weeks	3/11

MN: Minnesota; MIT: Massachusetts Institute of Technology; NJ: New Jersey; hemi: hemiplegia; quadri: quadriplegia; Contact: the robotic system uses the contact method to interact with the users (i.e., the participant's arm needs to physically contact the robotic arm); No-contact: the robotic system does not need to physically contact the users; hr: hour.

2. 상지재활로봇: 뇌성마비

- **Chen, Howard(2016): Effects of robotic therapy on upper-extremity function in children with cerebral palsy: A systematic review**
  - Kinematic duration, smoothness→ moderate to large effect size
  - Muscle tone→ moderate effect size
  - Clinical assessment→ variable

Outcome	Study	Robot system	N	Effect size [95% Confidence Interval]
Kinematics				
Duration	[38]	NJIT-RAVR	5	0.58 [−0.70, 1.86]
	[40]	InMotion2	13	0.71 [−0.09, 1.50]
	[41]	NJIT-RAVR	9	2.72 [1.36, 4.09]
Smoothness	[39]	InMotion2	12	0.86 [0.02, 1.71]
	[40]	InMotion2	13	0.65 [−0.15, 1.44]
	[41]	NJIT-RAVR	9	3.18 [1.69, 4.68]
ROM				
Supination	[37]	CosmoBot	6	0.46 [−0.69, 1.61]
	[38]	NJIT-RAVR	5	0.21 [−1.40, 1.83]
	[42]	NJIT-RAVR	2	−0.47 [−3.77, 2.83]
Muscle tone	[25]	InMotion2	12	0.42 [−0.39, 1.23]
	[40]	InMotion2	13	0.79 [−0.05, 1.63]
Melbourne	[38]	NJIT-RAVR	5	0.27 [−0.98, 1.52]
	[25]	InMotion2	12	0.31 [−0.49, 1.12]
	[42]	NJIT-RAVR	2	0.25 [−2.16, 2.66]
Fugl-Meyer	[25]	InMotion2	12	0.32 [−0.49, 1.13]
	[40]	InMotion2	13	0.89 [0.04, 1.74]

ROM: Range of motion; QUEST: Quality of Upper Extremity Skills Test; Melbourne: Melbourne Assessment of Unilateral Upper Limb Function.

2. 상지재활로봇: 뇌성마비

- **Bayon et al. (2016): Robotic therapies for children with cerebral palsy:**

  A systematic review

  - 2000~2015년 연구분석
  - QUEST, FMA 점수 향상
  - PEDI 향상

Device	Number of patients	Therapies and measurements	Results
InMotion2 [39]	12	Robotic therapy twice a week for 8 weeks	Improvements in total QUEST and Fugl-Meyer Assessment Scores
InMotion 3	-	-	Hasn't found any experiments with CP published in literature.
Hapic-Master [11]	9	Composite of 3 timed upper extremity tasks and several measurements of reaching kinematics	Improved in measures of motor activity in the MA
Armeo	-	-	Hasn't found any experiments with CP published in literature.
YouGrabber [44]	5	9 sessions of 45 min each one	Four of five patients showed improvements in all assessments (MA)
		The task carried out involved hand grasping and releasing, wrist pronation and supination and arm reaching	
REAPlan [45]	16	In robotic group, 8 users conducting 3 conventional therapy sessions and 2 robotic-assisted sessions per week over 8 weeks	Measures such as QUEST and PEDI were analyzed. There is evidence that robotic therapy is effective since outcome measures improved significantly more in the robotic group than in the control group.
			Long term effects of the therapy

2. 상지재활로봇: 효과

- **Weak evidence & Limitation**
  - 부족한 연구
  - 특정질환(stroke) 에 집중된 연구
  - 로봇보조 치료방법의 문제

    : 환자와 질환의 특성을 고려하지 않은 유사한 로봇 보조 치료방법

    : 로봇 보조 치료방법에 대한 상세한 기재 부족

    : 상지움직임의 반복 수행 외 고려되지 않은 사항(level of assistance, complexity of the movements, motivation)
  - 대부분의 로봇이 성인용

2. 상지재활로봇: InMotion

- No specific arm length for use (소아에게도 적용가능)
- Horizontal reaching movement
  - Fl & Ex in the shoulder & elbow (in the horizontal plane)
  - robot assist as needed.
- 충분한 반복운동 횟수
  - stoke Pt: OT- affected arm 의 30 회 반복동작/45분(Lang et al 2009),

    Robot -1000회 반복동작/45분(Lo et al. 2010)
  - CP Pt: RAT- 640회/60분 (Fasoli et al.2008)
- moderate to severe impairment 아동의 상지의 움직임과 협응 능력 향상을 기대
  - CIMT, bimanual training 의 기회가 없으나 재활 로봇 치료는 가능하게 하여 기능회복 기대

2. 상지재활로봇: InMotion

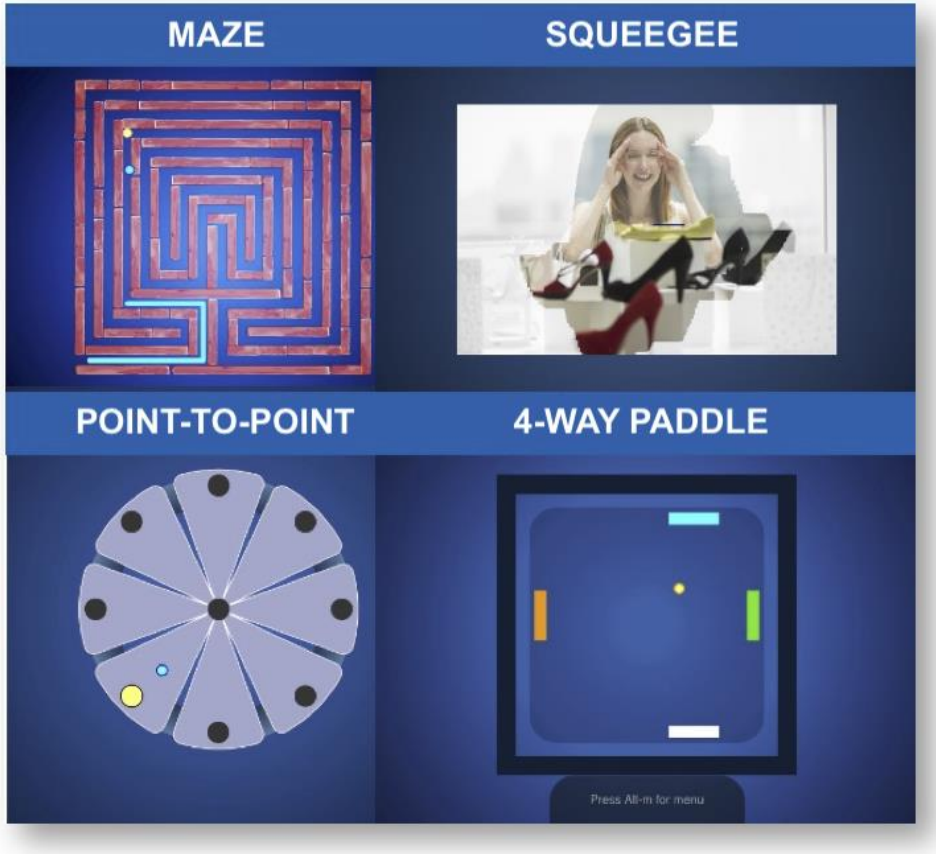
- **Effect**

  -motor planning

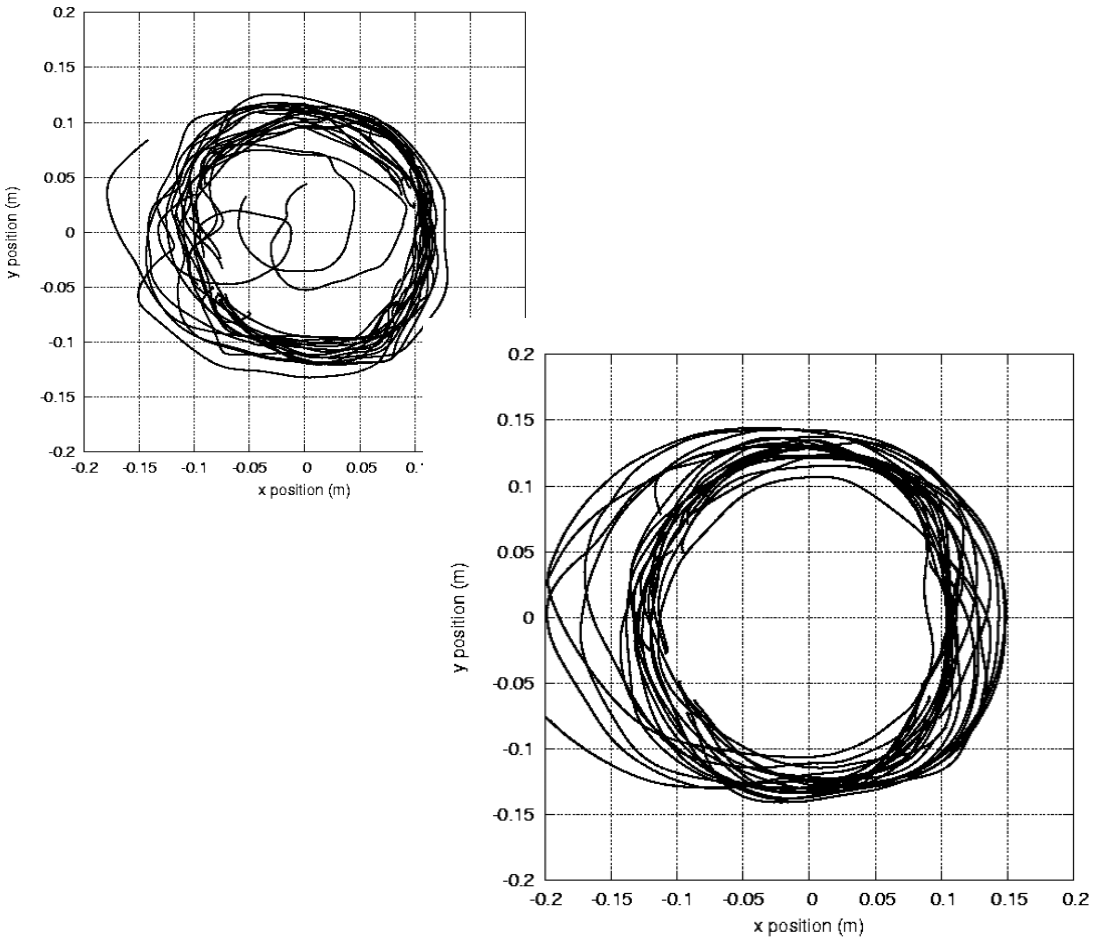
  -**Eye hand coordination**

  -Attention, visual field deficit

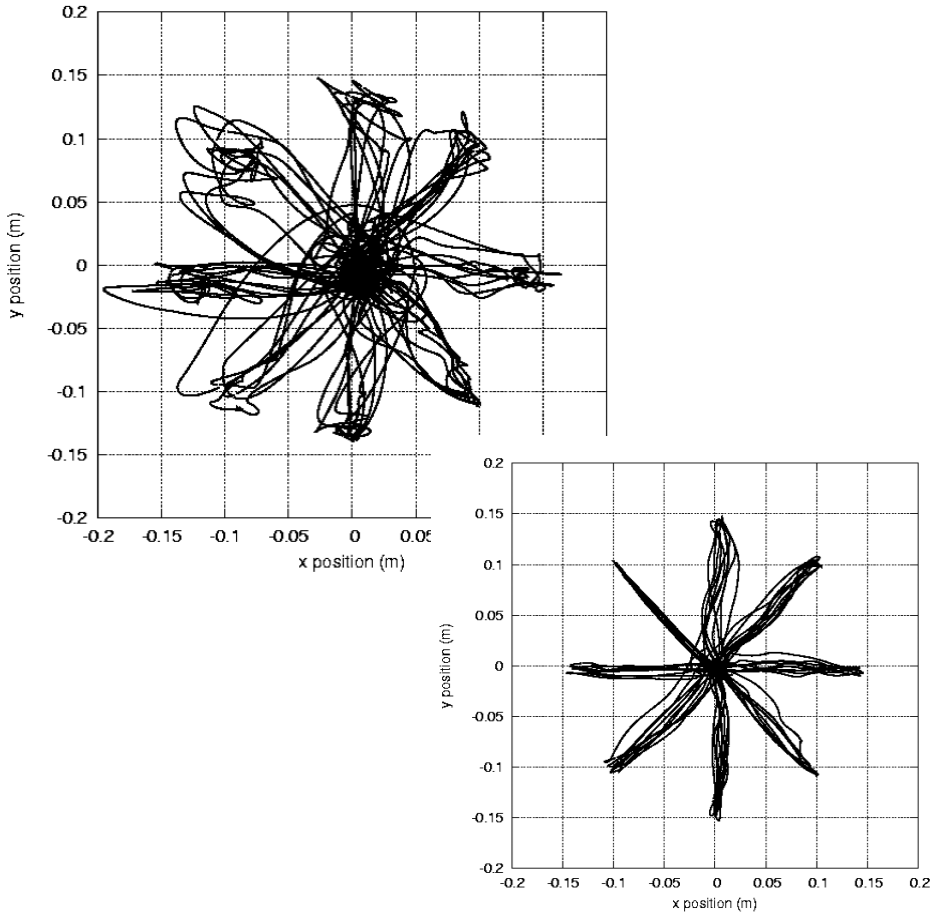
  -Massed practice



2. 상지재활로봇: InMotion



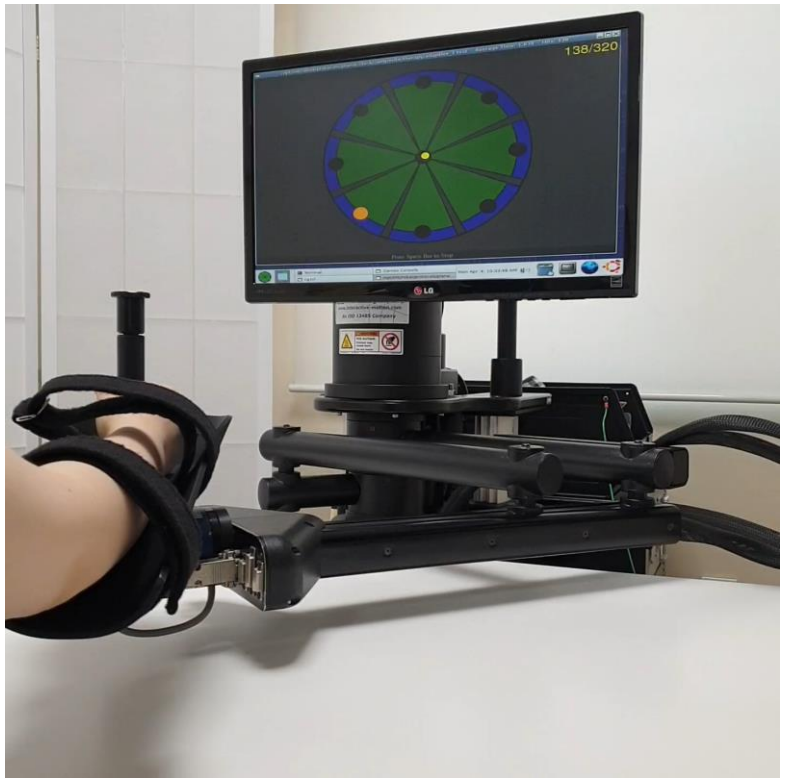
circle evaluation test



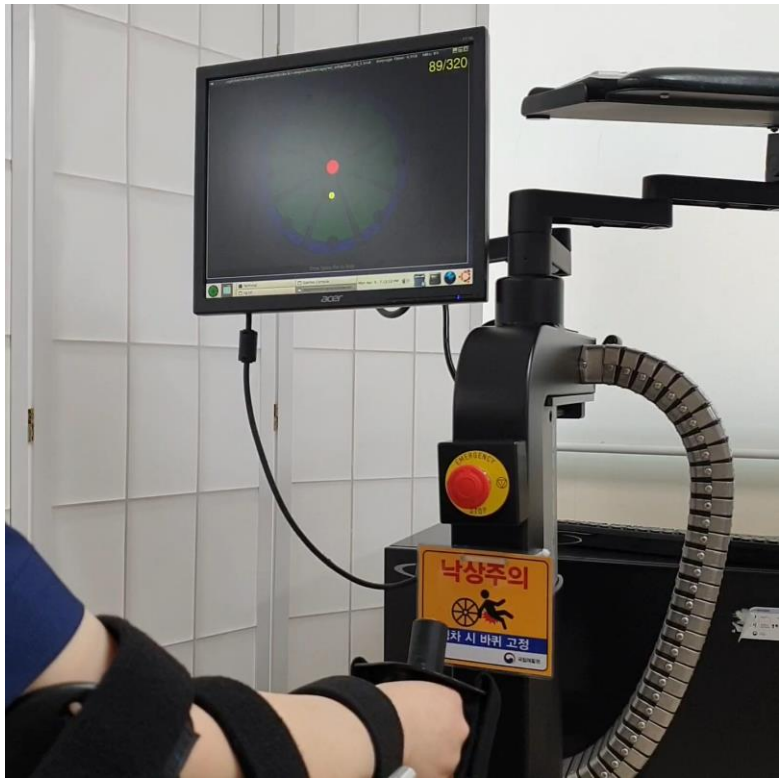
point to point test

2. 상지재활로봇: InMotion

InMotion ARM



InMotion WRIST



2. 상지재활로봇: Pediatric ArmeoSpring

- 6세 이상 사용 가능
- 어깨 팔 움직임과 함께 손의 쥐기 펴기 훈련 가능 (Pressure sensitive hand grip)
- Spring mechanism
  - Use a spring to create tensile strength, adaptive arm support for pediatric pateints without antigraivty strength.→ residual active movement 유도
- Proprioceptive, visual, auditory feedback 제공
  - Improving quality of upper limb movement, movement duration, velocity, smoothness, reduction of spasticity

2. 상지재활로봇: Pediatric ArmeoSpring

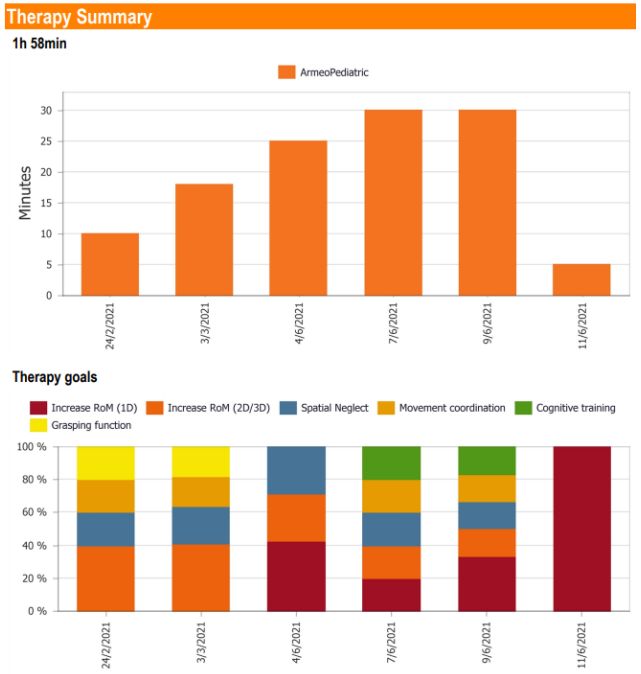
- **관련 연구**
  - Glavic et al.(2016) : 18years , CP hemiplegia → FM, FIM 점수 향상, MAS 호전
  - Peri et al. (2016): CP group→ Melbourne 점수, parameter 향상
  - Keller and van Hedel (2017): upper extremity task performance 향상, transfer, retention 효과
  - El-Shamy(2018): RCT 연구, Robot assisted therapy (15명)와 conventional therapy(15명) 비교 → MAS 감소, QUEST 점수증가, conventional therapy 와 통계적유의한 차이는 없음
  - Cimolin et al.(2019): CP hemi , 6ys~18yrs, control (normal) group 과 비교→ kinematic (movement duration, velocity, smoothness), QUEST, Melbourne assessment 향상

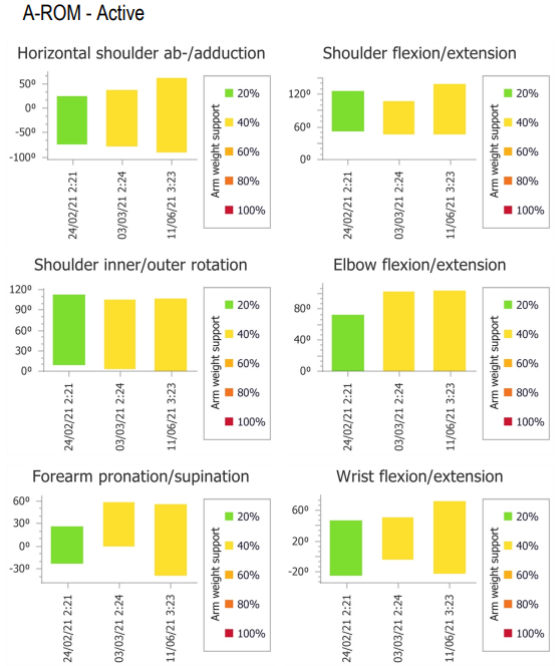
2. 상지재활로봇: Pediatric ArmeoSpring

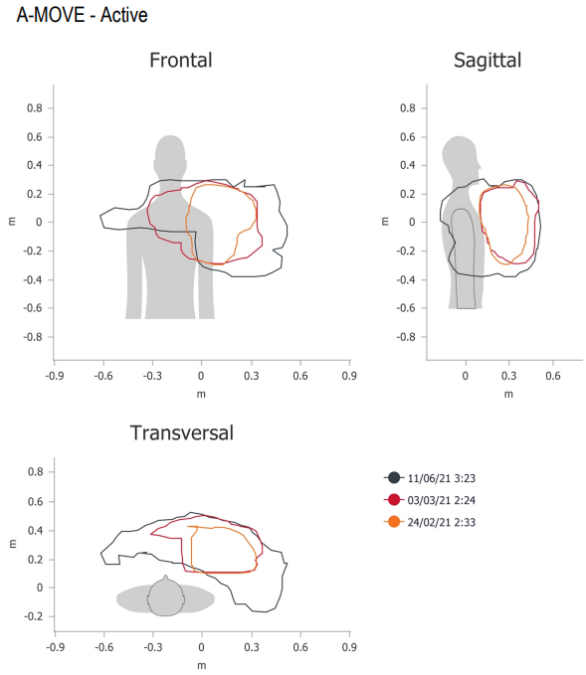
- **모듈길이조절**
  - Upper arm (1~ 12단계):155mm~235mm
  - Forearm (1~12단계): 233mm~370mm
  - 상지 무게 지지 값 설정: upper arm/forearm
- **훈련방법**
  - 1D exercise with single joint movement
  - 2D and 3D exercise with complex movement

2. 상지재활로봇: Pediatric ArmeoSpring

- **Report**
  - 환자의 A-ROM
  - 진행된 훈련프로그램







2. 상지재활로봇: Pediatric ArmeoSpring

ArmeoSpring: Shoulder& elbow

ArmeoSpring: Wrist & grasp

2. 상지재활로봇: ArmeoPower

ArmeoPower: no pediatric type

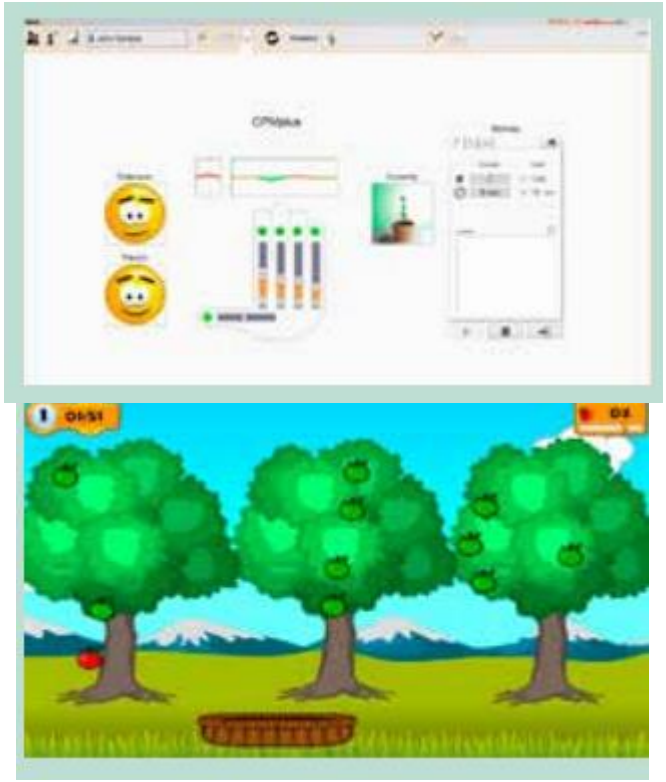
국립재활원 상지재활로봇치료실 (성인)

	Power	Spring	비고
MMT	>=poor	>=fair	•<poor인 경우 때때로 power 적용함 →support level high, 1D 게임 위주로 적용
MAS	<=2	<=2	
Shoulder pain	적용 고려	적용 고려	weakly pain 경우 통증이 유발되지 않는 범위 내에서 workspace 설정하여 적용함
Height	>150cm	>150cm	대부분 신장 150cm 이하의 경우 팔 길이 짧아서 axis 맞추기 어려움. 키가 작아도 팔 길이가 긴 경우에는 axis 맞추어 적용하기도 함.

2. 상지재활로봇: Amadeo

- **Assessment(fingers, thumb)**
  - active, passive ROM
  - Isometric strength
  - Spasticity: ROM at 3 speed
- **CPM therapy (continuous passive motion)**
  - speed, strength limit, wait time between movements
- **Assistive therapy**
  - 환자가 움직임을 시작하면 남은 필요한 움직임을 로봇이 시행함.

- **Serious game**



2. 상지재활로봇: Amadeo

Amadeo: assist mode

Amadeo: game

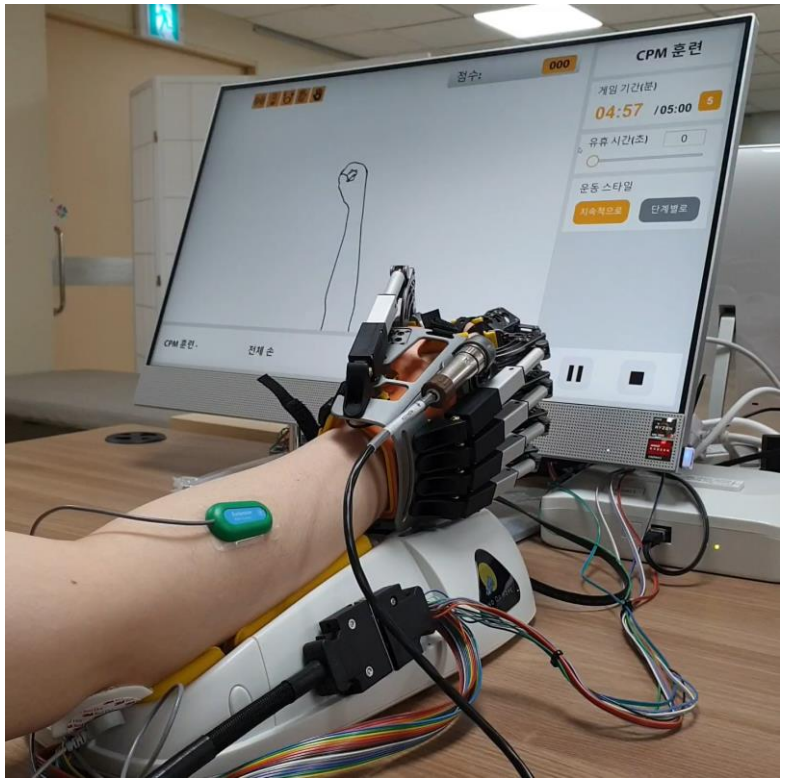
2. 상지재활로봇: Hand of Hope

- **신의료기술로 인정(신의료기술명: 근전도 구동 손 로봇 보조 재활치료): 2019.12월**
  - 기술명: 근전도 구동 손 로봇 보조 재활치료

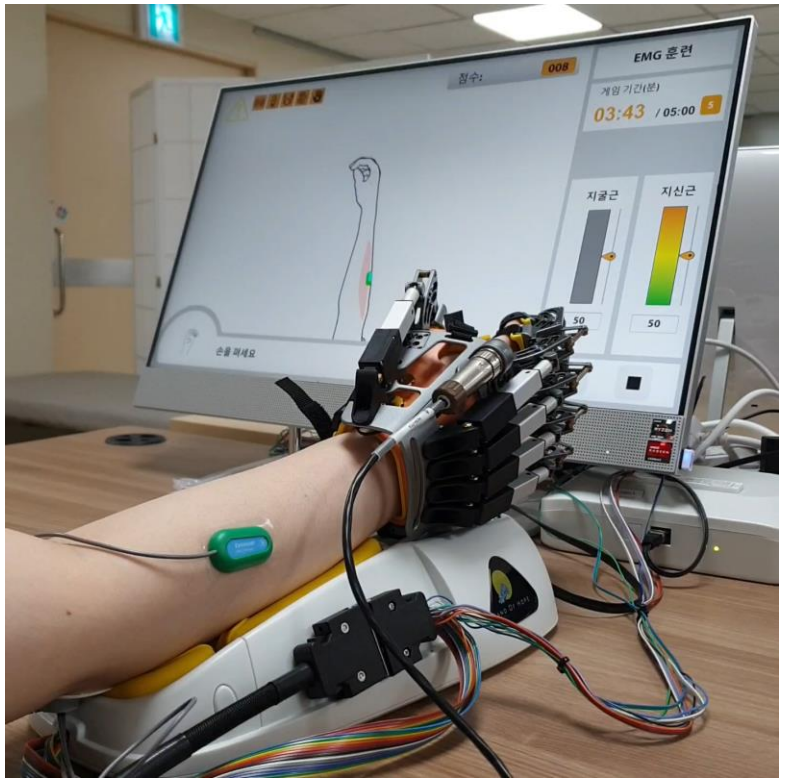
    (Electromyography-Driven Hand Robot-Assisted Rehabilitation Therapy)
  - 사용목적 : **상지 근력 강화 및 운동기능 향상**
  - 사용대상: **불완전마비가 있는 손 및 아래팔에 재활치료가 요구되는 환자**
  - 중재방법 : 근전도 구동원리(환자가 불완전 마비된 손을 자발적으로 움직이려 할 때 손가락 근 수축 신호를 감지하여 관절가동범위 전반에 걸쳐 보조력을 제공)를 이용한 손재활로봇으로 능동보조 및 능동운동을 제공함

2. 상지재활로봇: Hand of Hope

Hand of Hope: CPM



Hand of Hope: EMG



2. 상지재활로봇: RAPAEL Smart Kids

- **A sensor-based** rehabilitation training tool
- Forearm supination/pronation, wrist flexion/extension, and wrist radial/ulnar deviation
- 35 video games (e.g., fishing, sorting, driving, cooking, cutting, cleaning, painting, playing instruments, puzzle matching, etc.) designed to induce the targeted movement
- Chang HJ et al. (2020): conventional therapy 군 보다 smart glove 군에서 5 QUEST domain, 2 PEDI domain 에서 유의미한 향상을 보임.
- 홈 재활용 스마트글러브, 스마트 키즈, 스마트 보드 시판 허가(2021)

Figure 1. RAPAEL Smart Kids (Neofect Rehabilitation Solutions, Seongnam, South Korea)

2. 상지재활로봇: Smart Pegboard/ Board

- 훈련 목적에 따라 기능 훈련과 인지 훈련이 가능
- 시각 피드백, 청각 피드백

- 기능적 팔 뻗기 훈련
- 과제 지향적 훈련 게임

3. 상지재활로봇: 활용방안

- **앞으로 재활로봇 개발**
  - 경량화, 재료의 다양화, 의도파악, 인간-로봇 상호작용 관점의 피드백 방법에 대한 이슈
  - 소아용 재활로봇의 개발 필요성

  : 개발 시 고려되어야 할 사항

  - ✓ operability –must adapt to different children's ability and sizes
  - ✓ robot's weight- could obstruct the movement pattern of the limb, increase the energy consumption
  - ✓ safety
  - ✓ motivation

3. 상지재활로봇: 활용방안

Requirement	Definition	Example
Target group	Range of ages and problem of the users	ChARMin covered an age range from 5–18 years old [99]
Mechanical functionality	The device performance, including the controlling level of assistance, the functional workspace, smoothness of movement and robustness	McDaid designed a gait trainer that allows children to stretch their legs through the entire ROM and support body weight up to 80kg [40]
Weight	Total unsupported or unpowered mass of the device in relation to the user's body weight	Lerner developed a Bowden cable structure for an ankle exoskeleton with a weight of 1.85 kg and placed 65% of the total mass above the waist to minimise the metabolic cost of walking due to the device's weight [73]
Therapeutic benefit	The type of exercise that the rehabilitation system should promote and how this will improve the user quality of life	The paediatric Anklebot provided intensive task-specific sensorimotor therapy to the ankle of children with motor disabilities to promote motor learning [75]
Safety	The potential for the device to harm its user	IOTA device included a security stop button that immediately halts the servo motors [175]
Comfort	The user can use the device without physical pain or discomfort	The P-LEG robot used 3D printed braces based on 3D scans of the child's legs to improve the child's comfort [71]
Reliability	The consistency of the device operation in normal operating conditions	Laubscher designed a gait guidance controller to guide the motion of the patient's legs to follow healthy gait patterns to avoid unnatural gait patterns [176]
Operability	The device is easy to control and adaptable to changes in the user's ability and sizes	ATLAS exoskeleton used a slide and tubular regulation size system to adapt to the fast growth of the patients at all stages [177]
Product appeal	User satisfaction with the design, like fit, appearance, and sound of the device	One of the main requirements for PEXO was an appealing design, so the kidPexo version resembles a crocodile [26]
Quality of construction	Typical use and care should cause no damage, distortion, or hinder the expected useful lifetime of the device	PEXO device did not have electronics in the hand module, making the device water and dustproof [26]
Social acceptability	Matches user needs for discretion or attention to avoid stigmatisation	Weightman selected the handgrip of his robot through a questionnaire with different aspects like shape, style, feel, and colour [69]
Motivation	Encompass any aspect of the device considered to motivate the child	ChARMin used an Audio-visual interface with various game-based virtual reality scenarios to motivate the child for active participation [57]
Cost	The financial burden of the initial purchase and ongoing costs of the device	Volpini developed a low-cost robotic gait trainer to be used in developing countries [87]
Easy to maintain/repair	The ease of keeping the device fully operational, including when damaged	P-Legs' brace 3D print fabrication method made it easy to get new braces as the children grow [71]
Portability	The possibility of the device to be transported between locations	Cleary developed a smaller version of Pedbot that can be used at home [153]

Pediatric rehabilitation robots' requirements (Gonzalez et al. 2021)

3. 상지재활로봇: 활용방안

- **앞으로 임상연구 방향**
  - 로봇을 이용한 평가: Quantitative assessment of the patient's motor function(kinematic data. MMT, ROM..)
  - 로봇재활치료 방법의 구체화: duration, intensity, assistance, type of control, interactivity
  - Cognitive , physical engagement 강화 방법
  - Combination treatment 방법 모색 (tDCS, TMS, VR, BT..)

- **로봇의 기술적 특징을 잘 파악하여 치료 방법의 다양화, 구체화 하려는 노력**

요약

1. 소아에게 적용가능한 상지재활로봇의 종류가 적다
2. 소아 상지재활로봇 연구가 부족하다
3. 소아 상지재활로봇의 개발 및 연구의 활성화를 통해 치료효과에 대한 근거마련이 필요하다.

경청해 주셔서 감사합니다.