강의 10 생체 신호 기초 (Biomedical Signals , Biosignals)

학과 : 디지털의료융합학과
교과목 : 공학기초입문설계
강의자 : 한양대 ERICA 전자공학부 바이오로봇연구실 최영진
email : cyj@hanyang.ac.kr

The Nature of Biomedical Signals

- Living organisms are made up of many component systems:
  - For example, the human body includes the nervous system (신경계), the cardiovascular system (심혈관계), and the musculo-skeletal system (근골격계), among others.
  - Each system is made up of several subsystems that carry on many physiological processes (생리학적인 프로세스).
- Physiological processes are complex phenomena, including nervous or hormonal stimulation and control. Most physiological processes are accompanied by or manifest themselves as *signal* that reflect their nature and activities. Such signals could be of many types, including
  - biomedical (생체신호) in the form of hormones (호르몬) and neurotransmitters (신경전달물질)
  - electrical (전기신호) in the form of potential or current
  - physical (물리신호) in the form of pressure or temperature.
- Biomedical signal has the following forms:
  - continuous-time (연속시간) form : $x(t)$
  - discrete-time (이산시간, digital) form : $x(nT)$ or $x(n)$ with $nT = t$
    n : the index or measurement sample number of the array of values,
    T : the uniform interval (샘플링 타임) b/w the time instants of measurement.

10.1 Action Potential (AP)

- Online material : https://www.youtube.com/watch?v=oa6rvUJlg7o/
- The action potential (AP) is the *electrical signal* (전기신호) that accompanies the *mechanical contraction* (기계적 수축) of a single cell when stimulated by an electrical current.
- It is caused by the *flow* (이온 교환) of sodium (Na^+), potassium (K^+), and other ions across the cell membrane.
- The action potential is the *basic* component of all bioelectrical signals.
- It provides information on the nature of *physiological activity* (생리학적 활동) at the single-cell level.
- The signal consists of
  - resting potential
  - depolarization
  - repolarization
  - propagation of an action potential

- *Resting Potential* :
  - Nerve and muscle cells are encased in a semi-permeable (반투막) membrane that permits selected substances to pass through while others are kept out.
  - Body fluids surrounding cells are conductive solutions (전도성 용해질) containing ions.
  - In their resting state, membranes of excitable cells readily *permit the entry of K^+ ions, but effectively block the entry of Na^+ ions.* (세포막에서 K^+을 세포 내부로 받아들이고, Na^+을 세포 내부로 들어오는 것을 막는다)
  - The inability of Na^+ to penetrate a cell membrane results in the followings:
    * The outside of the cell is *more positive* than the inside of the cell. (세포 외부를 +로, 내부를 -로)
    * Charge balance cannot be reached due to differences in membrane permeability.
    * A state of equilibrium is established with a potential difference (전위차), with the inside of the cell being negative w.r.t. the outside.
  - Cell in its resting state is said to be *polarized*. (휴지 상태일 때 극성을 갖는다)
  - Most cells maintain a *resting potential* of the order of -60 to -100[mV] until some disturbance or stimulus upsets the equilibrium. (휴지 상태에서 세포 내부는 약 -70[mV] 정도를 유지)

- *Depolarization* :
  - When a cell is excited by ionic currents or an external stimulus, the membrane changes its characteristics and begins to allow Na^+ ions to enter the cell. (자극을 받으면 Na^+를 빠르게 세포내부로 받아들인다)
  - This movement of Na^+ ions constitutes an *ionic current*, which further reduces the membrane barrier to Na^+ ions.
  - This leads to an *avalanche effect* : Na^+ ions rush into the cell.
  - K^+ ions try to leave the cell, but cannot move as fast as the Na^+ ions. (K^+이 세포밖으로 이동하려 하지만 Na^+만큼 빠르지 못해서, 세포내부의 전위는 -에서 +로)
  - The net result is that the inside of the cell becomes positive w.r.t. the outside due to an imbalance of K^+ ions.
  - A new state of equilibrium is reached after the rush of Na^+ ions stop.
  - This change represents the beginning of the action potential, with a peak value of about +20[mV] for most cells. (Na^+의 이동이 멈춘 후에 새로운 평형상태에 이르는 데, 이때의 전위는 +20[mV] 정도이다.)
  - An excited cell displaying an action potential is said to be *depolarized*: this process is called *depolarization*. (세부내부의 강한 음극성이 약한 양극성으로 변화되었다는 의미)

- *Repolarization* :
  - After a certain period of being in the depolarized state, the cell becomes polarized again and returns to its resting potential via a process known as *repolarization*. (잠시후 다시 음극성으로 복귀)
  - Nerve and muscle cells repolarize rapidly, with an action potential duration of about 1[ms]. Heart muscle cells repolarize slowly, with an action potential duration of 150-300[ms]. (신경/근육 세포는 AP의 주기가 1[ms], 심장세포는 200[ms] 정도임)
  - The action potential is always the same for a given cell, regardless of the method of excitation or the intensity of the stimulus beyond a threshold: this is known as the *all-or-none* or *all-or-nothing* phenomenon. (AP은 세포가 한계치를 넘는 자극을 받을때는 자극의 강도에 상관없이 항상 같은 모양으로 생성된다)
  - After an action potential, there is a period during which a cell cannot respond to any new stimulus, known as the *absolute refractory period* (about 1[ms] in nerve cells). (AP를 생성한 바로 직후에는 다른 자극을 받아들이지 않는다. 신경세포의 경우 약 1[ms] 동안)

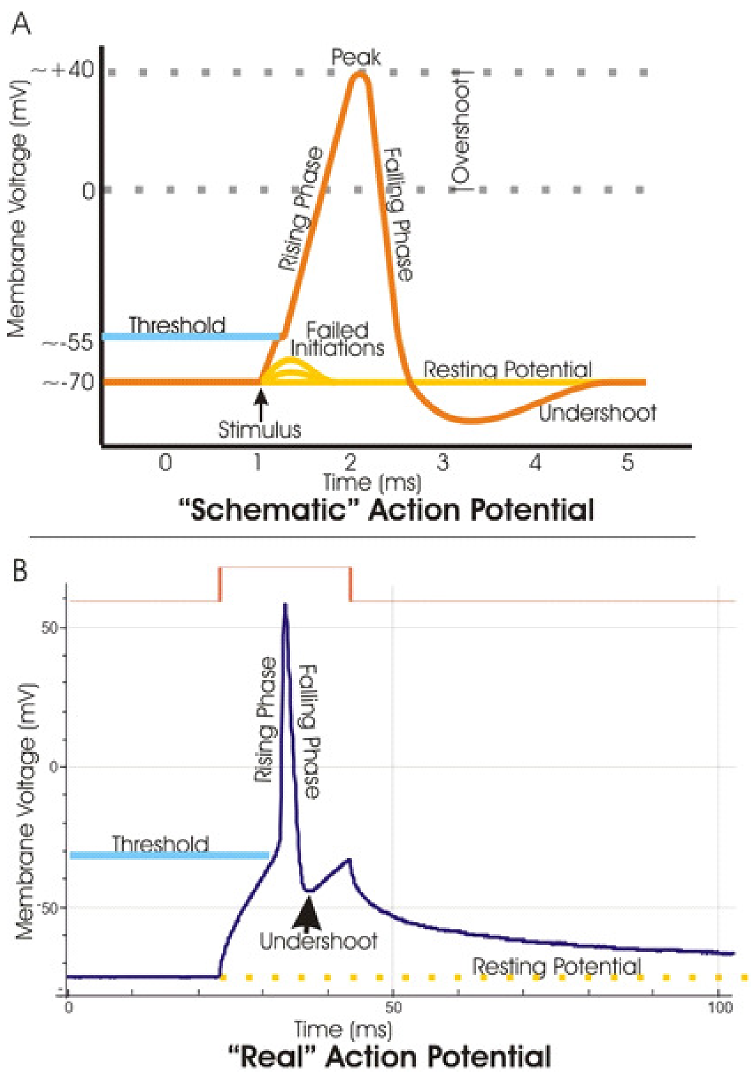

그림 1: Action Potential

- *Propagation of an action potential* :
  - An action potential propagates along a muscle fiber or nerve fiber as follow: Once initiated by a stimulus, the action potential propagates along the whole length of a fiber without decrease in amplitude by progressive depolarization of the membrane. (일단 자극에 의해 AP가 생성되면 이는 신경/근육 세포벽을 따라서 AP의 진폭 감소없이 전달된다.)
  - Current flows from a depolarized region through the intra-cellular fluid to adjacent inactive regions, thereby depolarizing them. (AP의 depolarization 상태에서 생성된 이온 전류가 인접한 세포를 자극하여 AP를 새롭게 생성시키는 방식으로 AP가 전달)
  - Current also flows through the extra-cellular fluids, through the depolarized membrane, and back into the intra-cellular space, completing the local circuit.
  - The energy to maintain conduction is supplied by the fiber itself. (AP의 크기가 일정한데, 이는 세포 자체로 부터 에너지 공급을 받기 때문)

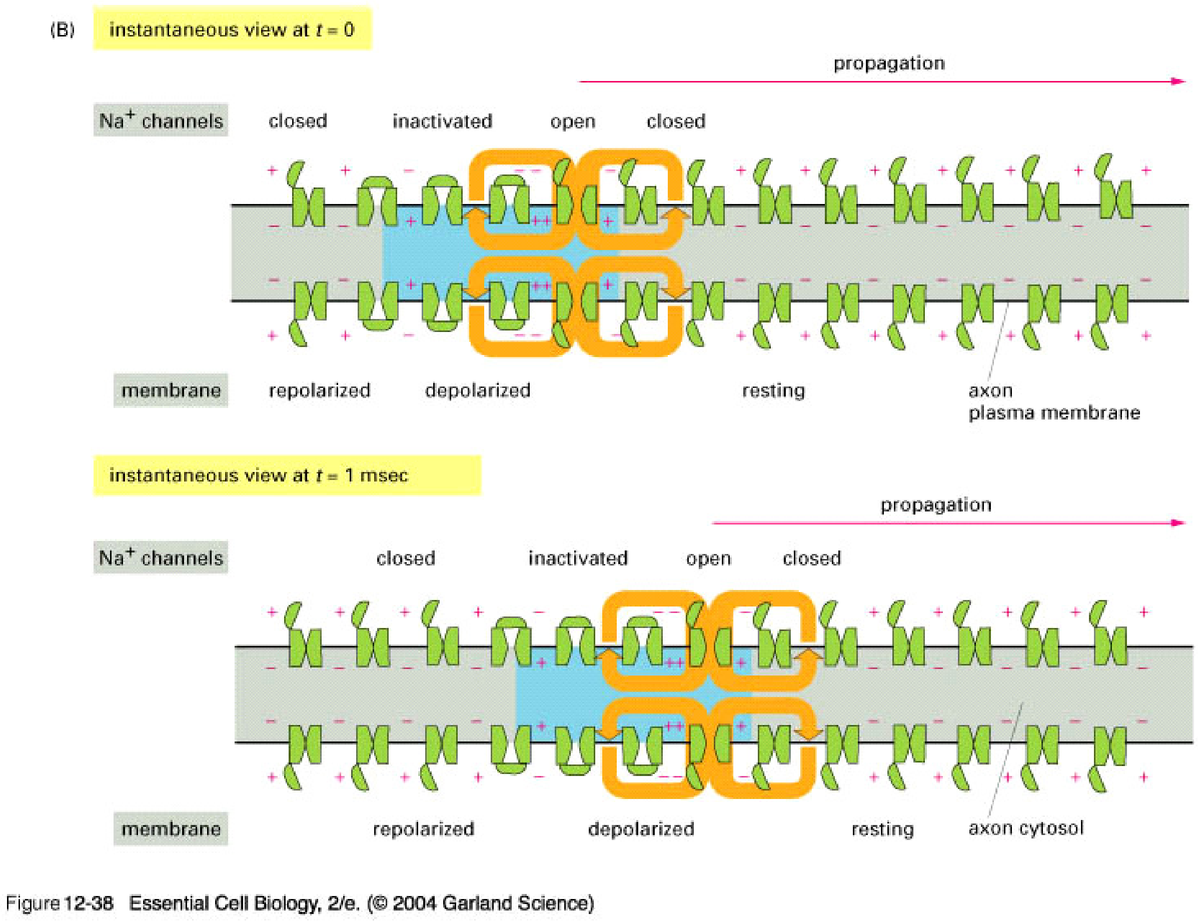

그림 2: Propagation of Action Potential Through Cell Membrane

10.2 Electromyogram (EMG), 근전도

- Skeletal muscle fibers (근골격 섬유) are considered to be twitch fibers because they produce a mechanical twitch response for a single stimulus and generate a propagated action potential. (기계적 수축과 AP를 전달)

- Skeletal muscles are made up of collections of *motor units* (MUs), each of which consists of an anterior horn cell (or motoneuron or motor neuron), its axon, and all muscle fibers innervated by that axon. (골격근들은 척수에서 뻗어 나온 anterior horn cell (이를 모터뉴런이라고도 함), 모터뉴런 핵이 있는 Axon, Axon에 의해서 신경이 심어져 있는 근섬유들로 구성)

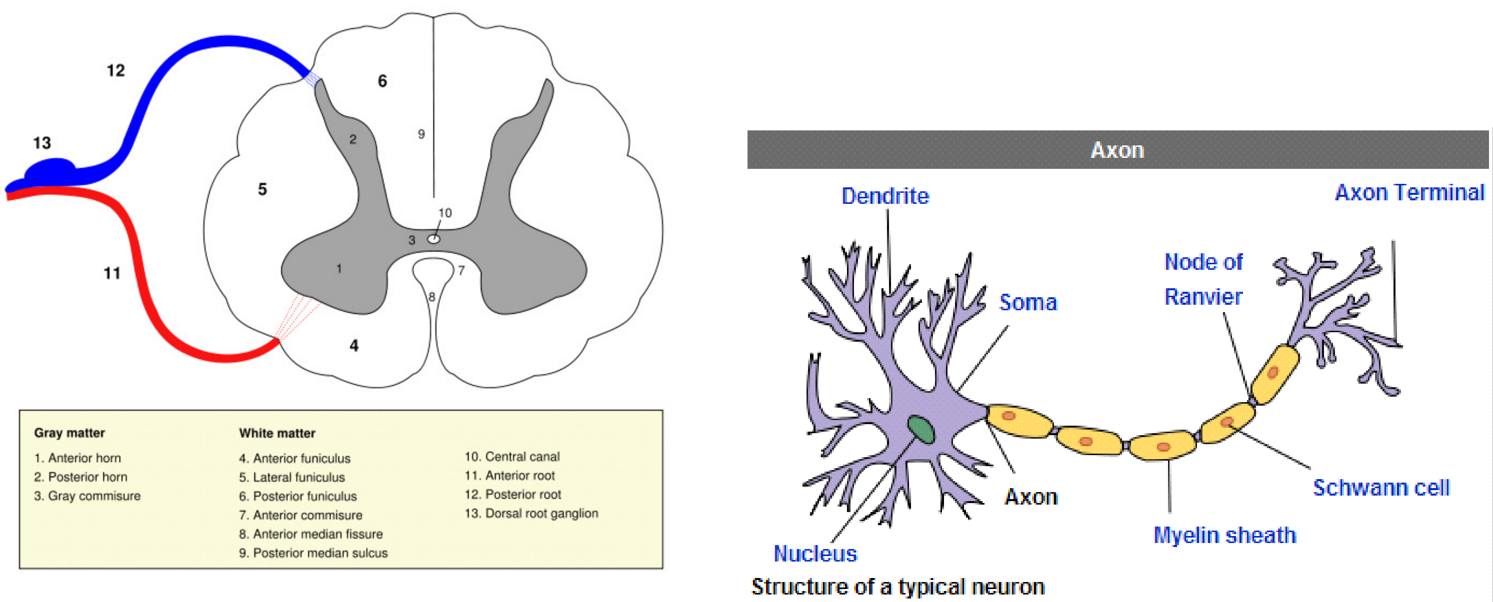

그림 3: Anterior Horn Cell (or motor neuron) and Neuron

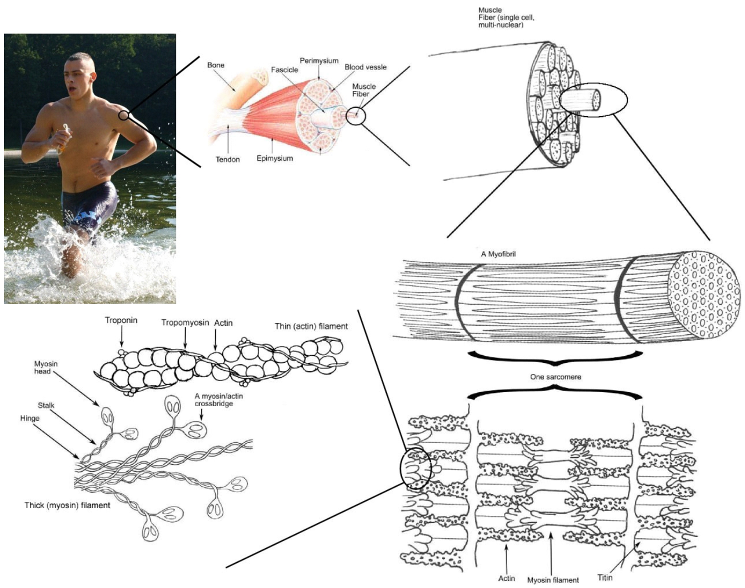

그림 4: Muscle Fiber

- A motor unit is the *smallest muscle unit* that can be activated by volitional effort. (MU는 의지에 의해서 제어되는 최소 근육 단위)
- Large muscles for gross movement have hundreds of fibers per motor unit; muscles for precise movement have fewer fibers per motor unit. (큰 동작을 하는 근육들은 하나의 MU에 의해서 수백개의 근섬유가 제어되며, 정밀한 동작을 해야하는 근육들에는 하나의 MU가 적은 수의 근섬유를 제어)
- The number of muscle fiber per motor nerve fiber is known as the *innervation ratio*. For example, it has been estimated that the platysma (of the neck) has 1826 large nerve fibers controlling 27100 muscle fibers with 1096 motor units and an innervation ratio of 25. (MU당 담당하는 운동 근섬유의 비율을 innervation ratio라 함, 작을 수록 정밀한 동작 가능)
- The mechanical output (contraction) of a muscle is the net result of stimulation and contraction of several of its motor units.

- When stimulated by a neural signal, each motor unit *contracts* and causes an *electrical signal* that is the summation of the action potentials of all of its constituent cells. This is known as the *single-motor-unit action potential* (SMUAP, or simply MUAP). (근육 또한 세포이기 때문에 자극을 받으면 수축하면서 전기신호를 생성한다, 이를 MUAP라 함)

- Normal SMUAPs are usually biphasic or triphasic, *3-15[ms] in duration*, *100-300[uV] in amplitude*, and appear with *frequency in the range of 6-30[Hz]*. (MUAP는 보통 2상(up-phase, down-phase)혹은 3상(up, down, undershoot)이며, 3-15[ms]의 duration, 100-300[uV] 진폭을 가짐)

- The shape of a recorded SMUAP depends on the type of the needle electrode used, its positioning w.r.t. the active motor unit, and the projection of the electrical field of the activity onto the electrode. (전극에 의해서 측정된 MUAP의 형상은 전극의 위치에 따라 다름)

- Motor units are activated at different times and at different frequencies causing asynchronous contraction. (MU는 신경 섬유에서 순차적으로 AP를 전달하므로 항상 다른 시간, 비동기 수축을 야기하면서 다른 주파수로 활성화 됨)

- The twitches of individual motor units sum and fuse to form tetanic contraction and increased force.

- Weak volitional effort causes motor units to fire at about 5-15[pps] (pulse per second). As greater tension is developed, an interference pattern EMG is obtained, with the constituent and active motor units firing in the range of 25-50[pps]. (약한 힘은 MUAP의 firing rate가 초당 5-15회 정도이지만, 강한 힘은 초당 25-50개 정도의 AP가 발생되어 근섬유에 전달된다.)

- Grouping of MUAPs has been observed as fatigue develops, leading to decreased high frequency content and increased amplitude in the EMG. (근섬유는 피로현상을 가지며, 이때 고주파 성분이 줄어들고, EMG의 진폭이 커지는 경향이 있다)

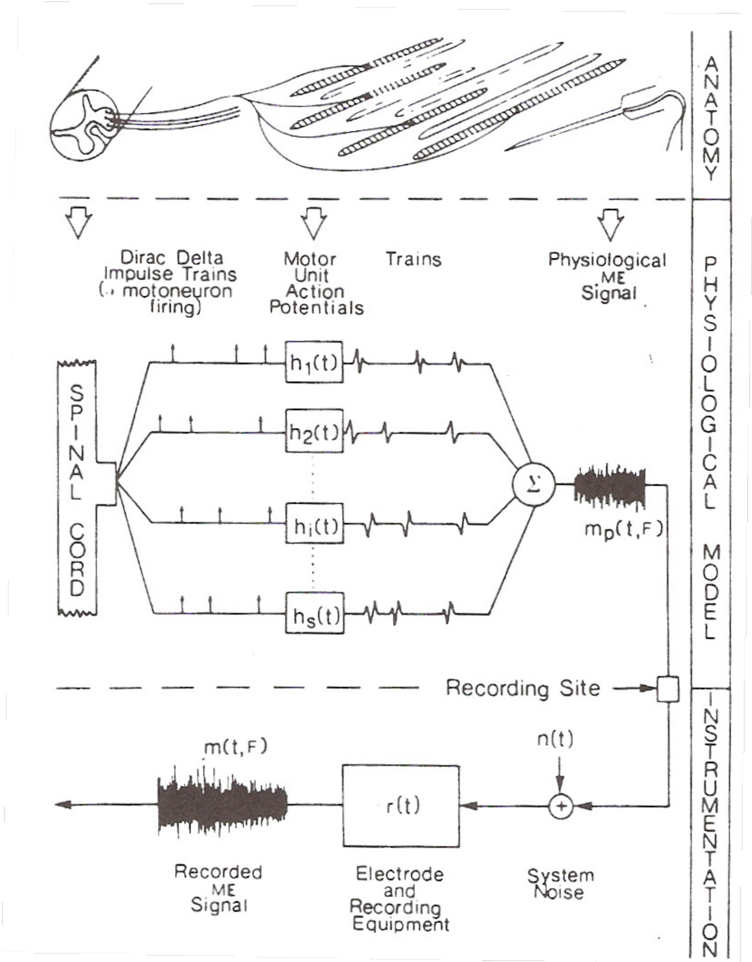

그림 5: EMG

- EMG signals recorded using surface electrodes are complex signals including interference patterns of several MUAP trains and are difficult to analyze.

10.3 Electroencephalogram (EEG), 뇌전도

- The EEG (popularly known as brain wave, 뇌파) represents the electrical activity of the brain. (뇌전도는 뇌의 전기적인 활동)
- The main parts of the brain are the cerebrum (대뇌), the cerebellum (소뇌), the brain stem (뇌간), and thalamus (시상).
- The cerebrum is divided into two hemispheres, separated by a longitudinal fissure (길게 갈라진 틈) across which there is a large connective band of fibers known as the corpus callosum (뇌량).
- The outer surface of the cerebral hemispheres, known as the cerebral cortex (대뇌 피질), is composed of *neurons* (grey matter, 회질) in convoluted patterns (난해한 패턴), and separated into regions by fissures.
- Beneath the cortex lie *nerve fibers* that lead to other parts of the brain and body (white matter, 백질).
- Physiological control processes (생리적인 제어), thought processes (사고, 생각), and external stimuli (외부 자극) generate signals in the corresponding parts of the brain that may be recorded at the scalp using surface electrodes.
- The scalp EEG is an *average* of the multifarious (다양한) activities of many small zones of the cortical surface beneath the electrode. (두개골에서 측정되는 EEG는 대뇌피질의 작은 영역에서 이루어지는 다양한 활동의 평균치를 의미한다.)
- For the *10-20 system* of electrode placement for EEG recording, refer to the corresponding figure.

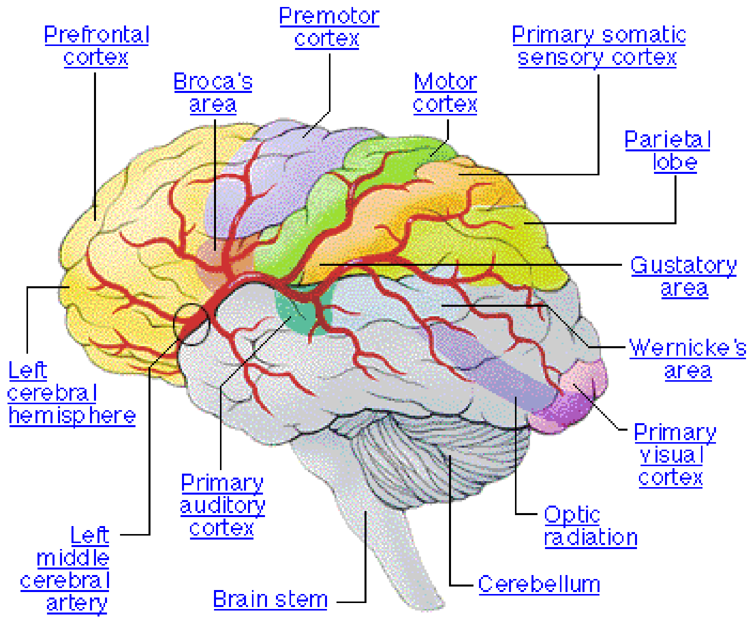

그림 6: Brain Map

- Typical EEG instrumentation settings used are lowpass filtering at 75[Hz]. (EEG 측정기에서는 75[Hz]이상의 고주파는 제거한다)

- EEG signals exhibit several patters of *rhythmic* or periodic activity. The commonly used terms for EEG frequencies (f) bands are:

  - Delta (δ) : $0.5 \leq f < 4$ [Hz]
  - Theta (θ) : $4 \leq f < 8$ [Hz]
  - Alpha (α) : $8 \leq f \leq 13$ [Hz]
  - Beta (β) : $f > 13$ [Hz]

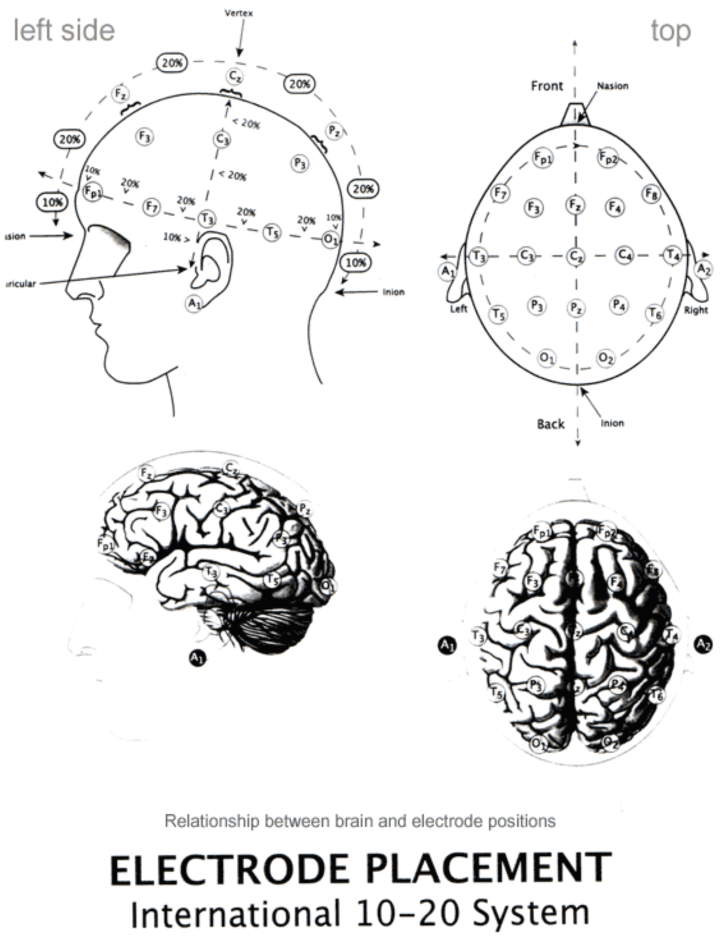

그림 7: 10-20 System

- EEG rhythms are associated with various physiological and mental processes. (EEG 리듬은 생리적 혹은 정신적 프로세스와 연관)
  - The *alpha rhythm* is the principal resting rhythm of the brain, and is common in wakeful, resting adults, especially in the occipital (후두) area with bilateral synchrony. Auditory and mental arithmetic tasks with the eyes closed lead to strong alpha waves, which is suppressed when the eyes are opened (that is, by a visual stimulus). (눈을 감고 쉬고 있을 때 알파파가 강하게 나타남)
  - The alpha wave is replaced by slower rhythms at various stages of sleep. Theta waves appear at the beginning stages of sleep. Delta waves appear at deep-sleep stages. (잠이 들면 주파수가 낮아짐: 알파 $\rightarrow$ 쎄타 $\rightarrow$ 델타)
  - High frequency beta waves appear as background activity in tense and anxious subjects. (베타파는 긴장상태, 일 할때)

10.4 Event-Related Potential (ERP), 유발전위

- The ERP (or evoked potential) includes the the EEG in response to light, sound, electrical, or other external stimuli. (유발전위는 자극에 대한 응답 전위를 의미)

- Short-latency ERPs are predominantly dependent on the physical characteristics of stimuli, whereas longer-latency ERPs are predominantly influenced by the conditions of presentation of the stimuli. (단기지연 ERP는 자극의 (빛, 소리 등)종류에, 장기지연 ERP는 자극의 존재 (impulse, step 등) 조건에 의존)

- Sensory evoked potentials (SEP) are recorded from the central nervous system following stimulation of sense organs, for example,

  - *visual evoked potentials* (VEP) elicited by a flashing light or changing pattern on a monitor (시각자극 CNS 응답)
  - *auditory evoked potentials* (AEP) by a click or tone stimulus presented through earphones (청각자극 CNS 응답)
  - *tactile or somatosensory evoked potential* (SSEP) elicited by tactile or electrical stimulation of a sensory or mixed nerve in the periphery (촉각자극 CNS 응답)

- (VEP의 예제, 한번씩 읽어보기) For visual evoked potential (VEP), you are placed in front of a computer screen, which shows a pattern of white and black squares like a chessboard, and a red dot in the middle that you are supposed to focus your eyes on with minimal movement. The procedure is done one eye at a time, with the eye that is not being tested blocked off with an eye patch. During the actual procedure, these squares alternate (white ones become black, black ones become white) at a rate of several times a second, which produces responses in the visual cortex, which is picked up by your skull electrodes. Since the computer controls the exact timing of the changes of the square colors, and receives the exact timing of the electric response in the corresponding electrodes, it is able to determine precisely the amount of time it takes for the visual stimulus to reach the visual cortex.

- *Motor evoked potentials* (MEP) are recorded from muscles following direct stimulation of exposed motor cortex, or transcranial stimulation of motor cortex, either magnetic or electrical. (운동피질에 대한 전기/자기 자극에 대해서 근육에서의 응답)

10.5 Speech signal, 목소리

- Speech sounds are produced by transmitting *puffs of air* from the lungs (폐) through the vocal tract (성도) as well as the nasal tract (비도) for certain sounds.
- The vocal tract acts as a *filter* that modulates the spectral characteristics (주파수 특성) of the input puffs of air. (성도가 필터 역할)
- It is evident that the system is dynamic and that the filter has the time-varying characteristics, that is, they are non-stationary

10.6 Vibromyogram (VMG)

- The VMG is the direct mechanical manifestation of contraction of a skeletal muscle, and is a vibration signal that accompanies the EMG. (근 수축시 EMG와 동시에 생성되는 기계진동 신호)
- The signal has also been named as the sound-, acoustic-, or phono-myogram.
- Muscle sounds or vibrations are related to the change in dimensions (contraction) of the constituent muscle fibers and may be recorded using contact microphones or accelerometers placed on the muscle surface. (VMG는 가속도계 혹은 마이크를 이용하여 측정)
- The frequency and intensity of the VMG has been shown to vary in direct proportion to the contraction level. (주파수와 신호강도가 근 수축량에 비례)
- The VMG, along with the EMG, may be useful in studies related to neuromuscular control, muscle contraction, athletic training, and biofeedback. (EMG / VMG를 함께 biofeedback에 이용)