# ARTIFACTS AND HOW TO AVOID OVERCALLING THEM

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## INTRODUCTION

Artifacts of some type are present in every EEG recording. EEG artifacts can arise from a variety of extracerebral sources, both physiologic and non-physiologic. Although the EEG technologist can recognize and either document or eliminate most artifact from the recording, the electroencephalographer must maintain a high level of awareness of potential artifacts. High quality EEGs are most likely to be recorded by a thoroughly trained and credentialed EEG technologist, working in a quiet, controlled environment with a cooperative patient. Unfortunately, many EEGs are performed by incompletely trained staff, in electrically hostile environments such as hospital rooms, intensive care units, and operating rooms, and on patients who are confused, agitated, or uncooperative. Thus, separation of artifact from true EEG signals is essential to avoid misinterpretation of EEG. Artifactual signals such as excessive muscle activity or patient movement can completely obscure the EEG, making interpretation impossible. More troublesome are EEG artifacts which mimic abnormal cerebral activity such as slow waves or spikes, leading to erroneous interpretation.

Artifacts in EEG can be divided into "non-physiologic" artifacts, generated by the EEG recording system itself or from the environment and nearby electrical devices. Non-physiologic artifacts often show random, bizarre, and non-stereotyped morphologies and therefore can be very difficult to recognize. Physiologic artifacts are generated by the patient's other biologic activity, such as muscle activity, eye movements, electrocardiogram, respiration, pulse and movement. These usually have stereotyped and fairly easily recognizable morphologies, aiding in identification. In some cases, physiologic artifacts can actually aid in EEG interpretation by helping to define state changes (eye movements, respiratory changes).

## NON-PHYSIOLOGIC ARTIFACTS

**Instruments**. Instrumental artifacts can originate from nearly any point between the patient's scalp-electrode interface and the final display of the EEG. Amplifier "noise" is small random fluctuations in amplifier output created by thermal agitation of electrons in the circuits of the EEG amplifiers. This noise is not apparent at usual recording sensitivities, but can be seen at the 1-2µV/mm sensitivities used for coma and electrocerebral inactivity (ECI) recordings. Amplifier nose should not exceed 2µV, measured peak-to-peak. Metal corrosion can occur in electrode wires, the connections between wires and cups, in the receptacles of jackboxes, and in connection points of metal cables. Worn or frayed cables and broken cable connections can introduce significant artifact, particularly during ambulatory or inpatient video-EEG monitoring. In some cases, loose or detached EEG machine components can cause complete loss of signal. This is particularly common in portable equipment that sustains repeated vibration and movement shocks. Finally, misplugged electrodes or incorrect software settings (filters, sensitivity, montages) can result in unusual and hard-to-detect artifacts.

**Electrodes**. Impedance testing measures electrode impedance, or opposition to alternating current flow, and evaluates the contact between the electrode and the scalp[1]. The impedance of each electrode should be between 100 and 5,000 ohms. High and unequal electrode impedances impair the common mode rejection feature of the differential amplifier and allow electrical interference to contaminate the recording[2]. Higher electrode impedances can distort the EEG, either by introducing 60 Hz artifact, or by attenuating voltages. Low electrode impedances are usually caused by short circuits between adjacent electrodes.

Electrode pops or electrode artifacts may be caused by a poor scalp-electrode interface, resulting in intermittent electrode movement and disruption of the electrical double layer between electrode and scalp. This results in a sudden, sharp vertical transient, usually positive in polarity, restricted to a single electrode. Electrode pops often have a characteristic shape, but loose electrodes may cause bizarre repetitive waveforms which can mimic focal slowing or epileptiform activity. In this case, the lack of a "physiologic field" in neighboring electrodes can help to confirm artefactual origin. Electrode artifacts may also arise from damaged electrode wires or pins, or by faults within the EEG jack box. These artifacts also involve a single electrode, without a physiologic field, but they may be difficult to locate and correct.

Photoelectric or photovoltaic artifacts are typically seen over frontal electrodes during photic stimulation, as a brief spiky transient simultaneous with the flash of light. These artifacts are caused by minute photochemical reactions in the electrode and electrolyte solution and are seen when electrode impedances are high. A “ground lead recording” occurs when the impedance of one active electrode is extremely high. In this case, the ground electrode becomes an active electrode, replacing the very high impedance electrode. Since the ground electrode is often placed over the frontal region near Fpz, this can result in the surprising appearance of eye movement artifacts in other regions of the head.

Salt bridges occur when the electrolyte solution under one electrode contacts the electrolyte of adjacent electrodes. This creates one giant recording area, with no difference in potential between the adjacent electrodes, and a “flat” channel.

**Environment**. Environmental sources of artifact include electromagnetic noise, radiofrequency noise, and ground loops. Electromagnetic noise can be produced both by intentional radiator devices such as radio and television transmitters, radio transceivers, cellular phones, or wireless broadband, and by unintentional radiators such as computers, televisions, office equipment, fluorescent lights, powered machines, and power lines. Radiofrequency interference is propagated by radiation and by conduction over signal lines and alternating current power systems. The most ubiquitous environmental noise is 60 Hz artifact, or “line noise”. This is electrostatic interference caused by capacitance between 60 Hz conductors and other conductors that act as the second place of a capacitor, such as EEG electrode wires, metal bed frames, metal equipment, and other materials around the patient. This may be most prominent in electrode pairs with mismatched impedances, and can be reduced by application of a 60 Hz filter. Artifacts may be produced by equipment near the patient, such as intravenous infusion pumps, respirators, dialysis machines, cutting or coagulating electrode systems, percussive bed devices, and other medical equipment. Artifact may originate from either the machine’s motor, or from movements of part of the equipment or liquid within the equipment located near the scalp electrodes. For example, infusion pump artifact may arise from the rotating motor[3], or from electrostatic charges on drops within the IV line itself[4]. Similarly, respirator artifact can be produced by electrostatic charges of water in the respirator tubing or from the motor of the respirator.

## PHYSIOLOGIC ARTIFACTS

A variety of artifacts can be caused by other physiologic electrical fields generated by the patient.

**Muscle**. Electromyogram (EMG) artifact consists of usually fairly low voltage, very brief, high-frequency potentials[5]. EMG artifact is often maximal over the frontal and temporal regions from forehead tension, squinting of the eyes, and clenching the teeth. This can be reduced by asking the patient to open the jaw slightly. Chewing can cause bursts of high voltage EMG artifact over both temporal regions every 1-2 seconds, while swallowing may cause longer duration lower voltage artifact over the temporal regions. Bruxism can cause bursts of EMG activity alternating from side to side[6]. EMG artifact is usually easy to recognize because of its typical morphology and very rapid frequency, but bursts of EMG can mimic epileptiform activity. This is particularly true for eye muscles, which may generate extremely sharp muscle potentials called “rectus spikes”. EMG potentials can be distinguished from epileptiform activity because of short duration (2-20 msec) and extremely spiky appearance, variable morphology, and reduction or disappearance during sleep[7]. EMG artifact can be reduced by decreasing the high frequency filter to 35 or 15 Hz, but this can often cause the artifact to appear as low to moderate voltage beta activity.

Occasionally, repetitive motor unit potential firing can cause stereotyped artifact resembling train tracks, or can mimic periodic epileptiform discharges. Specific patterns of EMG artifact may suggest a secondary diagnosis, such as myokymia, hemifacial spasm, or Parkinsonian tremor.

The photomyoclonic response is bursts of EMG activity from the frontalis and orbicularis oculi muscles during photic stimulation. The EMG bursts have a latency of about 50 msec from the photic flash.

Bursts of EMG activity during nonepileptic psychogenic events show a characteristic pattern on time-frequency mapping, with a stable, non-evolving frequency that is different from the evolving pattern seen during an epileptic seizure[8].

**Eye movements**. The eyes are electrically charged structures and their movements generate changing electrical fields. The eye is a dipole: the cornea is positive and the retina negative. The dipole is seen only when the eye moves. Both lateral and vertical eye movements can cause characteristic deflections on EEG. Eye movement artifacts are typically seen over the front of the head in the channels closest to the eyes, FP1, FP2, F7 and F8, and are bilateral and Synchronous[9]. Using additional channels (electrooculogram, EOG) to monitor eye movements can distinguish eye movements from frontal or anterior temporal cerebral potentials. Unusual eye movement artifacts can occur when one eye is missing or injured or the retina is abnormal (loses electrical dipole) or when there is a defect in frontal bones. Common artifacts include those with opening and closing eyes (blink artifact), fluttering of the eyelids (at frequencies from 1 to about 15Hz), vertical and horizontal eye movements (slow lateral eye movements during drowsiness, rapid vertical and lateral eye movements during rapid eye movement sleep, saccadic eye movements during scanning or reading, and nystagmus)[10]. During blinks, the eyeball rotates upward (Bell's phenomenon), causing the positive end of the dipole to approach the frontal electrodes. Therefore, there is a symmetric downward (positive) deflection maximal in Fp1 and Fp2. During lateral eye movements, the maximal deflections are seen in F7 and F8.

**Electroretinogram**. The electroretinogram is a mass electrical response of the retina to photic stimulation. When seen in EEG electrodes, maximal in Fp1, Fp2, and EOG electrrodes, the ERG is usually of much lower amplitude than when recorded directly from the cornea. Two waves can be identified; the a wave or first large negative component, and the b wave which is corneal positive, larger in amplitude, and longer in duration. This can be confirmed by holding an opaque card over one eye and then the other during photic stimulation; ERG will disappear in the covered eye.

**Tongue movements**. The tongue also has an electrical field, with the tip negatively charged. Tongue movement or glossokinetic artifact can produce repetitive or intermittent slow activity (2-6 Hz), often with a characteristic square shape broadly over both frontal regions[11]. This can be reproduced by asking the patient to repeat words that produce active tongue movement, like 'lilt' or 'ta-ta-ta'. Similar artifact can be seen with infants sucking while feeding or on a pacifier, and by sobbing or hiccups.

**Cardiac**. The heart's electrical activity is another source of spiky potentials[12]. The cardiac QRS complex creates an electrical field that can be detected by EEG, most commonly by referential electrodes placed on the ears. The electrical field of the heart usually extends only to the base of the skull, but may propagate more widely in patients with short thick necks. The electrocardiograph (ECG) signal is recorded in an additional channel so that cardiac artifacts can be identified by comparing the deflections in the cerebral channels to that in the cardiac channel. ECG artifact is usually easily identified, but may be more difficult to recognize when the heart rhythm is irregular or when the QRS has variable morphology. Respiration may cause variability in the electrical axis of the heart, resulting in variable amplitude of the ECG artifact. ECG artifact can be reduced by using bipolar recording montages and by turning the head or extending the neck.

When scalp EEG electrodes overlie small arteries, pulse artifact may also be seen as slow waves with a peak 250-300 msec after the peak of the QRS. This can occur in any lead, and may affect several neighboring electrodes. Ballistocardiographic artifact is a widespread artifact caused by low-amplitude movements of the body during each heartbeat, and is typically only seen when recording at very high sensitivity.

**Body movements**. Movements of the head, body, and limbs can produce high voltage irregular potentials. These are commonly seen during both epileptic and nonepileptic events, and may obscure the recording[13]. Artifacts from shivering and rigors can also produce widespread artifacts.

Rhythmic or semi-rhythmic artifacts may be caused by patient movements, such as breathing, especially during hyperventilation, crying, and hiccups. During respiration, there may be fairly rhythmic slow activity seen in a widespread distribution, synchronous with body movement. At other times, sharp or slow waves may be seen in posterior electrodes, seen as the patient's head rocks on the electrodes during respiration. The EEG technologist can aid in identification of such artifacts by marking inspiration and expiration on the EEG tracing, or by placing a respiratory monitor. Rhythmic artifacts may also be caused by patting of neonates and infants, cardiopulmonary resuscitation efforts[14], and by chest physiotherapy[15], percussive beds, and oscillatory ventilators[16].

**Altered tissue impedance**. Breach artifact is caused by a skull defect. Bone typically attenuates faster EEG frequencies; consequently, a skull defect will increase the amplitudes of the underlying frequencies. A breach rhythm consists of a focal increase in beta activity or accentuation of mu-like rhythms in the central and temporal regions, with intermittent slow waves or sharp transients. Reduced amplitudes can be seen with subgaleal and subdural hematomas, which have high electrical conductivity and facilitate volume conduction of EEG activity.

**Sweat artifact**. Sweat artifact is commonly seen in hot environments, in tense patients or hospitalized patients with fever. Artifacts are caused both by low frequency potentials generated by sweat glands, and by interaction of the electrolyte solution, lactic acid from sweat, and electrode metals to produce large but very slow (0.25-0.5 Hz) baseline sways[17].

**AVOIDING MISINTERPRETATION OF ARTIFACT Recording techniques to reduce or eliminate artifact**

Recognition of artifact requires skilled EEG technologists and electroencephalographers. EEGs should be performed according to established guidelines and using standard electrode positions[18-20]. This ensures good scalp-electrode contact, low electrode impedance, and symmetrical electrode placement, thus avoiding many electrode artifacts. Routine EEG records from 21 scalp electrodes placed according to the International 10-20 System, using anatomical bony landmarks on the skull[21]. In addition, ground and reference electrodes are placed. Ground electrodes reduce electrical interference. Additional electrodes may be useful in identifying biologic artifacts, or in determining the state of the patient. Such electrodes may include electrocardiogram (EKG), eye movement monitors or electro-oculogram (EOG), electromyogram (EMG), and respiratory monitors. The EEG technologist should note the presence of any skull defects, scalp edema, or other monitoring devices on the head, as these may cause altered tissue impedance with resultant amplitude and frequency abnormalities. The technologist should also note when electrodes have to be moved from the standard 10-20 positions because of scalp or skull defects, and should move the homologous electrode in the other hemisphere to preserve recording symmetry.

An alert technologist should recognize potential artifacts and take steps to reduce or eliminate artifact. While troubleshooting artifact, the technologist should systematically check the electrodes (including ground, reference, and electrode impedances), the EEG machine (including the jackbox, amplifier, all cables, the power source, and the display output), the patient, and the environment. For example, a channel with excessive 60Hz artifact suggests high electrode impedance, which can result in spurious waveforms. When 60Hz artifact is present, therefore, the technologist should check electrode impedance, then re-prep the scalp to reduce electrode impedance and re-apply the electrode. If artifact persists, the electrode should be replaced and the pins and jackbox receptacles checked to eliminate equipment malfunction as the cause of artifact. Severe artifact with minor patient movements suggests poorly affixed electrodes; electrodes should be reapplied and in some cases attached with collodion or other adhesives to prevent electrode movement. The EEG technologist may also be able to identify other sources of artifact and reduce them, such as by moving other electrical equipment away from the patient or unplugging it to eliminate 60Hz or other mechanical artifact, asking the patient to slightly open the mouth and relax the jaw to reduce facial EMG artifact, or emptying water out of respiratory tubing to remove electrostatic artifacts. When artifacts cannot be eliminated, the EEG technologist should annotate the EEG whenever potential artifact occurs. Such artifacts might include glossokinetic artifact from talking, eye movements, limb movements, or respiratory movements. In some cases, use of supplementary recording electrodes (e.g. limb, electrooculogram, respiratory monitors) may aid in identification of artifact. EEG technologists should be encouraged to carefully investigate any potential sources of artifact, and should be given continuous feedback about their performance in recording high-quality EEGs and identifying or eliminating artifact.

EEGs recorded in the patient's home[6], epilepsy monitoring unit, intensive care unit (ICU)[22], and operating room (OR)[23] may be especially susceptible to artifact[24,25]. The long duration of recording often results in abundant electrode artifact, which may not be able to be corrected if an EEG technologist is not immediately present. Use of adhesives for electrode application is essential in these cases. Asking the patient and family members to keep a log of the patient's activities can help identify potential sources of artifact such as patient movement or environmental artiacts. ICUs and ORs are electrically hostile environments, with multiple pieces of medical equipment, wireless devices, and multiple electrical lines.

**Reviewing techniques to identify artifact**

Use of digital EEG equipment can aid in the detection of artifact by allowing the electroencephalographer to adjust sensitivity settings, filters, and montages during EEG review[26,27]. Such manipulation can better define or eliminate artefactual signals[28]. For example, a 20Hz filter could be transiently applied to reduce EMG artifact during an electrographic seizure. A suspected epileptiform discharge should be viewed in several montages to confirm that it maintains a physiological field. Spiky potentials which "disappear" when viewed in a new montage are most likely artifactual. Digital reformatting improves EEG interpretation. One study[28] showed that interrater agreement for “as-acquired” digital EEG was the same as for paper EEG, with weighted kappa scores of approximately 0.65. When electroencephalographers were given the ability to reformat the digital EEG, however, interpreter agreement improved to kappa scores of 0.8. Montage reformatting was most useful for distinguishing normal variants from abnormal patterns, identifying artifacts, and classifying abnormalities as focal or generalized. Use of concurrent video recording allows the reviewer to determine if an EEG transient corresponds to patient movement or other environmental events.

Any waveform which cannot be immediately identified during review should be assessed in detail. Features which can help to confirm a waveform to be artifact include:

1. Amplitude. Waveforms which differ significantly in amplitude from those in other adjacent channels are often artifactual.
2. Field. EEG signals have an electrical field which extends over the scalp in a predictable manner – with a point of maximal electronegative or electropositive voltage and decreasing voltage with increasing distance from this maximal point. Waveforms which are present in only a single electrode (i.e. do not have a “believable” or physiologic field), or which show multiple points of maximal electronegativity or electropositivity over different head regions (causing multiple phase reversals in bipolar montages) are usually artifactual as well. Unusual waveforms which are seen in all channels simultaneously are often the result of an artifact in reference or ground electrodes, or in the jackbox or amplifier cables
3. Morphology. Most EEG waveforms have a characteristic morphology, while artifacts can cause unusual wave shapes and excessively spiky potentials. 4. Frequency. The duration of a waveform can also be useful to determine artifact, especially EMG artifact, which usually has a frequency of 2-20Hz.

<u>Montages</u>

A montage is a specific layout of the amplifier output (derivation) of pairs of electrodes (channels). Montages create a 2 dimensional map of the activity recorded between pairs of electrodes. Each display type has advantages and disadvantages in representing EEG activity. A variety of montages (at least 3 - 2 bipolar and 1 referential) should be used during EEG recording in order to accurately represent the 3 dimensions of brain activity[29]. Many more montages can be applied during review to identify and localize specific EEG waveforms.

In a bipolar montage, channels are created from electrodes that are adjacent to one another on the scalp. These are typically arranged in chains, with each channel incorporating 1 electrode from the previous channel, e.g. F1-F3, F3-C3, C3-P3, etc. Bipolar montages at are best for display of highly localized EEG waveforms. Bipolar montages can include chains in either the longitudinal (front to back) or transverse (coronal) directions. In referential montages, each electrode is compared to the same “reference” electrode, which can be either a single scalp electrode (common reference, such as Cz, A1 or A2), or an average of activity from all electrodes on the scalp (average reference). Reference montages are optimal for displaying widespread EEG activity, but all channels are affected by any activity present at the reference electrode, whether this is artifact or the waveform of interest.

Unpaired longitudinal or transverse montages arrange channels in anatomical neighboring sequences, usually left to right or front to back. These electroanatomical montages produce the least distortion of voltage representation, but make it difficult to detect asymmetries. Paired-group montages arrange electrodes from homologous areas of the scalp together, such as left and right temporal or left and right parasagittal. These produce some distortion of voltage representation, but better assessment of symmetry. Paired channel montages place single channels from homologous brain regions next to each other, usually in straight lines in the temporal or parasagittal chains. Paired channel montages produce the most voltage distortion, but best symmetry display.

Montage reformatting. Since digital EEG data is acquired using a hard-wired referential montage (Input 2 for all channels is the machine reference, or REF), the computer can perform calculations on the stored data to create any desired montage. For example, transforming the recorded montage to a bipolar montage requires the following calculations:

| Channel | Recording montage | Calculations | Display montage |
|---|---|---|---|
| 1 | Fp1-REF | Fp1-REF – (F7-REF) | Fp1-F7 |
| 2 | F7-REF | F7-REF – (T3-REF) | F7-T3 |
| 3 | T3-REF | T3-REF – (T5-REF) | T3-T5 |
| 4 | T5-REF | T5-REF – (O1-REF) | T5-O1 |
| 5 | O1-REF | | |

Additional references can be easily constructed by taking the average of data from two or more electrodes[30].

Sensitivity

In analog EEG, sensitivity is the input voltage (μV) divided by the output pen deflection (mm). For example, a 50μV signal at a sensitivity of 7μV/mm would be 7.1mm high. In digital EEG, the same waveform on the display may not actually measure 7.1mm. Rather, the amplitude scale is displayed as a vertical icon (calibration line) on the monitor, and the amplitude of EEG signals is determined relative to this reference amplitude. The scale can be changed to provide a variety of sensitivity settings. Most programs also contain a feature that allows a user to draw a line from peak to trough of any given waveform to get a numerical value for the amplitude in microvolts.

Sensitivity changes can be performed in two ways with a digital EEG machine. The technician can use a software sensitivity switch during EEG acquisition to change the actual amplifier sensitivity. During acquisition or review, the display sensitivity can be changed. To decrease the amplitude of the waveforms on the page, the software program plots each data point on the monitor as if it were half as large (Figures 6 and 7). Sensitivity changes can be made for a single channel, groups of channels, or the entire page. Sensitivity changes can be useful in allowing the electroencephalographer to see the entire waveform morphology and avoid overlapping of adjacent channels.

Time scale

On paper EEG, a paper speed of 30 mm/second was standard, writing 10 seconds of EEG per paper page. Most EEG software programs display EEG at 10 seconds “per page” or per monitor screen. The number of seconds displayed per page can be adjusted, however, to optimize interpretation. For example, displaying 20 seconds or more per page (slow paper speed) will enhance slow activity and allow analysis of slow periodic complexes or prolonged events such as seizures. Spreading out to the EEG to show only 2 to 5 seconds per page will spread out faster frequencies, similar to increasing the paper speed on an analog machine. This allows more precise analysis of time relationships of signals in adjacent channels. In addition, time cursors can usually be placed on the screen to measure time relationships exactly. Many software programs allow the number of seconds per page to be varied from 1 to 100 seconds.

Filters

After amplification, the EEG signal is filtered to exclude frequencies outside the range of interest. This allows the EEG signal to be reproduced without contamination by environmental noise. Three filters are typically used: the low frequency filter (LFF) or high-pass filter, the high-frequency filter (HFF) or low-pass filter, and the 60Hz notch filter. Each of the filters is designed to attenuate, or decrease the amplitude of, frequencies above or below a specific cutoff frequency. Filters are not absolute. At the cutoff frequency, they attenuate the output signal to approximately 70% of the input signal, while frequencies above or below the cutoff frequency are attenuated to a greater or lesser extent depending on the filter type[31].

The low frequency filter reduces the size of slow waves and excludes direct current. The cutoff frequency is the frequency at which sine waves are reduced in amplitude by a set percentage, typically 30.3% or 3dB (sometimes 20%). Typical LFF filter settings are from 0.3 to 1Hz. Frequencies below the cutoff frequency are attenuated by more than 30%, while frequencies above the cutoff frequency are attenuated by less than 30%. Low frequency filters are useful in minimizing slow skin and scalp potentials, and in reducing slow electrostatic artifacts caused by movement of electrical fields around the patient.

The high frequency filter reduces the size of fast waves. The cutoff frequency is again the frequency at which sine waves are reduced in amplitude by a set percentage, usually 30.3% or 3dB (sometimes 20%). The typical HFF filter setting is 70 Hz. Frequencies above the cutoff frequency are reduced by more than 30%, while frequencies below the cutoff frequency are attenuated by less than 30%. High frequency filters reduce artifact from muscles.

Filters distort time relationships between waves of frequencies near the cutoff frequency, an effect called phase shift or phase distortion. The LFF attenuates slow waves and moves the peak of the slow waveform backwards in time (phase advance). The HFF attenuates fast waves and delays the initial deflection from baseline, moving the peak of the fast waveform later in time (phase delay). Phase shift is more noticeable on slow waves, and may affect the relationship of peaks of slow waves in adjacent channels.

The 60 Hz or notch filter attenuates electrical artifact produced by alternating current line frequencies (60Hz in US, 50Hz in Europe). This filter is sharply tuned to attenuate the amplitude of sine waves at 60Hz, but it does have some effect on frequencies above and below 60Hz. It should not be used routinely, as it may mask high impedance electrodes and affect the sharpness of epileptiform discharges.

Digital EEG instruments initially filter the EEG using analog filters. Filters switches are controlled by software and can be applied to individual channels or for all channels simultaneously using a master command. In contrast to analog machines, digital EEGs are usually acquired using broad bandpass filter settings, typically 0.1 to 100Hz. EEG data is stored using these initial broad filter settings. After conversion of the analog signal into a digital signal, software filters are applied during review[32]. Digital filters affect only the display, not the underlying stored data. Therefore, filters can be applied and removed as needed. Digital filters are computer programs or algorithms designed to remove unwanted frequency components from a signal, and their effect on the EEG signal mimics high frequency, low frequency, or notch filters[33]. There are three common types of digital filters: 1) finite impulse response (FIR) filters, 2) infinite impulse response (IIR) filters, and 3) frequency domain filters using the fast Fourier transform (FFT). As opposed to analog filters, digital filters (FIR and FFT) can be designed to cause no phase distortion, so that time relationships are preserved even when filters are changed. Digital filters can also be designed to have very sharp cutoff frequencies, much sharper than the typical 6dB-per-octave roll-off of analog filters.

Display

The quality of digital display of EEG depends on several factors. First, the sampling rate and the resolution of the analog- to-digital converter determine the horizontal and vertical coordinates for reconstruction of the EEG signal. High sampling rates and resolutions better than 0.5µV produce more continuous-looking outputs. The video controller card and the software outputting the EEG signal to the video card can also influence the appearance of digital EEG.

Monitor size and resolution are the most important determinants of display quality[34]. The resolution is expressed as the number of vertical and horizontal points or pixels. Dot pitch is the diagonal distance between displayed pixels. The smaller the pitches, the higher the screen resolution. The output of the analog to digital converter is plotted on the monitor. If the sampling rate is 240Hz, a total of 2400 horizontal samples are produced every 10 seconds. Currently available monitor resolutions range from 800 to 1600 horizontal pixels, or points. Therefore, not every sample can be displayed if the EEG is reviewed at 10 seconds per screen. Most software programs display every other (or every 3rd) point or an average of two adjacent points. Decreasing the number of seconds per screen can allow display of every data sample point. A minimum of 100 pixels per second is recommended. Similarly, the vertical pixel limitation will affect the visual resolution of signal amplitude. Digital EEG typically has 32 channels or more available for display. If the vertical resolution is 1200 pixels, this allows 37 pixels for each channel. If a signal of 200 microvolts is displayed, each pixel will represent 5.5 µV. This has the same effect as having inadequate resolution of the analog-to-digital converter. Decreasing the number of channels or using a "zoom" feature can overcome this limitation.

Common monitor resolutions include VGA (640 x 480 pixels), Super VGA (800 x 600 pixels), extended Super VGA (1024 x 768 pixels), TIGA (1280 x 1024 pixels), and XGA (1600 x 1200 pixels). The current minimum resolution of reading stations should be 1,600 × 1,200 pixels and the screen size should measure 20 inches diagonally or more[35].

Although color is commonly used to group channels in montage displays, this can result in subtle alterations in the appearance of certain frequencies. Use of black traces on a light background is optimal for review.

As opposed to analog EEG, digital EEG display is not limited by vertical or horizontal misalignment problems, and strict time relationships between channels can be maintained. Because data acquisition is not limited by pen response times, very high frequency events can be faithfully represented if appropriate display resolutions are used. Finally, digital displays can be altered in multiple ways to improve horizontal and vertical resolution and optimally reproduce EEG signals.

**CONCLUSION**

Artifacts are ubiquitous in EEG recording. Constant vigilance by a qualified EEG technologist is required to obtain high quality recordings, identify artifacts at the time of recording, and eliminate the sources of artifact if possible. During review, the electroencephalographer should reformat the EEG to be sure that any unusual waveforms represent true brain activity rather than artifact. When in doubt, conservative interpretation as probable or possible artifact is preferred to misdiagnosing a patient with focal or epileptiform abnormalities which may not exist.

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