Principles and Practice of Clinical Electrophysiology of Vision

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49

Causes and Cures of Artifacts

Geoffrey B. Arden

Different artifacts occur in different situations, and it is convenient to consider these in turn.

ARTIFACTS OCCURRING IN A NEW CLINIC

In a new clinic the user will have to purchase equipment. It should not be assumed too readily that the equipment actually works! If at all possible one should use similar equipment, in a department where it is known to be functioning well, before making any purchase. If the equipment has not been used before, it should be installed by the makers, who should give demonstrations that the equipment works and describe how it works. Many manuals are so poorly written that they are only useful when you already know more or less what to do! Some tests for proper functioning are described below. Remember, computer-driven equipment may have some bugs in the program, and program updates may produce bugs in a previously well behaved program or may even introduce viruses.

While software faults can produce artifacts that may be irregular and difficult to analyze, the most common reasons for recording artifacts are due to poor techniques. An important part of the clinic is the rooms in which the equipment is housed and the tests performed. In general it is not necessary to have screened rooms that electrically isolate the equipment and patient from other sources, but it is wise to take precautions in a clinic that is being newly furbished. If a coaxial lead is attached to the input of a cathode ray oscilloscope (CRO) and the other end terminated with a few centimeters of wire attached to the braid of the shield, this will act as a "hum tracer." The wire can be carried round the clinic and any localized source of electrical interference detected. Other building faults that may escape attention and lead to anomalous results are sources of light present in rooms that should be dark: residual glow or light leakage around fittings in false ceilings can cause small elevations of the dark-adapted threshold, and if equipment is placed inside the patient cubicle, indicator lamps and light from the display screens can have the same effect. Such light leaks may make it impossible to elicit the threshold scotopic response.

However, the most common troublesome artifact is mains interference. A simplified description of the cause of this interference is given below. One should ensure that electrical power outlets do not form a source of mains interference. They should be checked to see that they are properly grounded, and the supply should be totally enclosed by metallic conduit or trunking that has also been properly grounded. Ideally, the electrical supply of the clinic should be separate from other sources and taken from the main service panel of the building. A separate and heavy grounding cable that leads out of the building is also helpful. If separate circuits are not available and the power supply is contaminated by other users' equipment, a large and heavy isolation transformer may be required to act as a filter.

Any equipment near the patient can be a source of mains interference. If an apparatus is turned off and yet remains connected to the power outlet, it can introduce electrical interference. Equipment that uses considerable current, for example, motors used in elevators and commercial kitchens, can cause mains interference, even when placed a floor above or below the clinic. In many test situations, it is desirable to have the room lights turned on. Fluorescent tubes are arcs that produce pulses at double the mains frequency, and this may be a troublesome source of artifact. New varieties that operate at 40 K Hz are now readily available. The high-frequency pulses are more easily filtered from records. Interference of still higher frequency and intensity can be generated by medical pagers and similar sources: they produce broadcast signals that are designed to pass through walls and be picked up under adverse circumstances. The broadcast frequency is high, and the type of recording equipment in common use picks up and rectifies the envelope of the pulses. Fortunately, they are intermittent, for little can be done to remove the interference. Another source of interference that may be neglected is the power supply of a personal computer. These are almost always of the "switching" type and produce fast radiated spikes. These can cause noise on visual displays.

When an old disused facility is reinstalled, all of the above applies. In addition, remember that equipment that has not been used deteriorates, and "well it *was* working" is a statement to be treated with suspicion. Most commonly, records suddenly start to contain artifacts after periods of satisfactory use. The most frequent consists of mains interference, but slow drifts of voltage or higher-frequency noise may be encountered. If a sudden loss of all displays occurs, that does not count as recording an artifact and is beyond the scope of this chapter.

THEORY OF MAINS INTERFERENCE

The cause of mains interference is diagrammed in Figure 49–1. When current flows through a device, electromagnetic radiation is radiated at right angles to the direction of current, according to well-known rules, and spreads to the recording site, in this case a patient's head. Within these tissues flows a small induced current. In another mode, the electrostatic voltage of the patient is altered because he forms one plate of a condenser, with the electrical equipment acting as the other plate and the intervening air as the dielectric. If metal plates are interposed between the source and the patient, he can be isolated from both electrostatic and electromagnetic radiation, although the latter is much more penetrating. Evidently, it is pointless to use shielding if a new source is placed between it and the patient, but in most screened rooms, one finds electrical cables and equipment inside the shield! With good equipment, such shielding is not often necessary. If it is, then the shield must be grounded so that induced currents and voltages in the shield are taken to ground. Often shielding need not be complete. A heavy metal couch, properly grounded, diverts radiated current away from the patient. Sheets of fine copper mesh in the form of roller blinds can be used and are effective, although not opaque. Various types of conductive glass are available, and these also act as shields. They are particularly useful in reducing emissions from monitor screens. The glass is often coated with a fine layer of tin alloy that is transparent and conductive; such sheets are expensive.

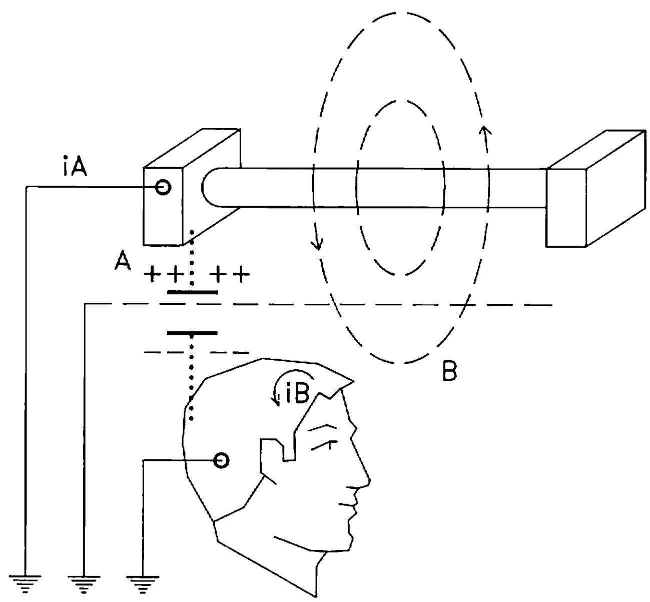

FIG 49–1.
How mains interference enters the recording situation. **A,** electrostatic interference. **B,** electromagnetic. The shield (*dotted line* connected to the central ground) will prevent electrostatic interference but only reduce electromagnetic radiation.

It is important that screening and other equipment be grounded in a proper manner. In Figure 49–2, the patient is connected to a piece of equipment that injects a weak current into him. This is not a fanciful situation—all "real" amplifiers do just this—and current sources may be produced in a variety of other ways. The current return path is through the ground to the patient and then back through the ground of the equipment. This forms a *ground loop,* a most frequent cause of interference.

The causes of such loops may not be obvious. For example, a patient's moist hand touching a ground point may cause one. Frequently, the power supply of an apparently grounded item is a cause of a loop. In environments with many different pieces of

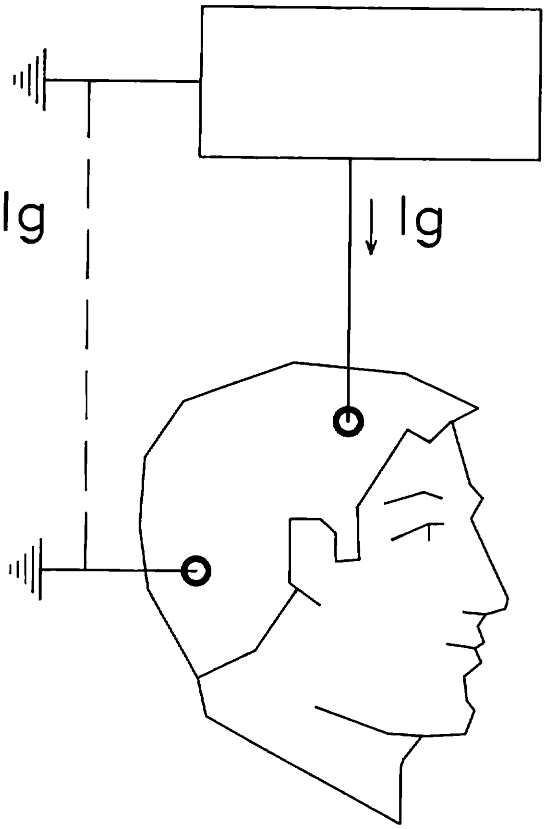

FIG 49–2.
A ground loop. Current injected into the patient from any source flows through the tissues and sets up voltage gradients.

equipment such as operating theaters, loops are more difficult to eradicate. Since current (usually at mains frequency or a multiple of it) continuously flows through the loop and the patient, electrodes placed along the current path record interference. Providing all precautions are taken and safety rules followed, the following general temporary procedure will localize loops and assist in their removal: make a new ground connection to all equipment. Use thick, flexible, insulated wire to make a very low resistance connection to each metallic portion of chairs, equipment racks, and all separate items of equipment. Check that the resistance between each of these grounds and all the other is very high (i.e., only one ground for each item). Connect all the separate wires to a common point, the ground terminal of the lowest-level (input) amplifier. Then remove all other grounds, including all those in power cables, except for the main amplifier. If a loop is the source of the problem, the mains pickup will vanish or be much reduced. By replacing the old grounds one at a time the fault can be localized. Modern equipment is rarely dangerous if run without grounds (double insulation). A word of warning is required. If mains cables are modified in this way and the instruments used routinely in such a manner, there is a high probability that sooner or later someone will remove the new ground attached to the amplifier's front end, and then the equipment would be totally ungrounded. This is illegal in many countries and might be dangerous, so once the fault has been found, it should be corrected and a standard system installed.

DOUBLE-SIDED AMPLIFIERS AND MAINS HUM REDUCTION

Figure 49–3 illustrates the principle of the double-sided or differential amplifier. The biological signal is developed down a resistance R_1 and little biological current flows down the resistance R_2 in series. The voltage across $R_1 + R_2$ is measured because the ground is connected to the far end of R_2. For example, R_2 and the ground electrode may correspond to placing a clip on the ear. If electrostatic or electromagnetic pickup produces a current that flows through *both* R_1 and R_2 and if $R_2 > R_1$, the mains voltage artifact may be quite large. To minimize the interference, it is usual to differentially record across R_1. In the diagram, the one side of the amplifier measures ${}_AV_E$ and the other, ${}_BV_E$: the quantity amplified is ${}_AV_E - {}_BV_E = {}_AV_B$. This will reduce the mains interference by $R_1/(R_1 + R_2)$. An amplifier that does this is called a differential amplifier, and all modern equipment uses such amplifiers. While this may seem evident, errors in electrode placing are in fact quite frequent[1, 4] and can lead to artifactual results.

The ability of a differential amplifier to reject signals that are presented to both its A and B inputs is called the common-mode rejection ratio (CMRR). Manufacturers are prone to quote very high figures for the CMRR. Such figures are often meaningless since the measurements are made under unreal conditions. Figure 49–3 shows the input of a "real" amplifier. The electrodes are connected to the source by resistances R_e, which represent the resistance of the electrodes and tissues. Since amplifiers are not perfect, some current flows into or out of the amplifier. This can be represented by a resistance to ground R_g, the input impedance of the amplifier. R_g is made as high as possible because otherwise the signal current produces a voltage that is divided between the two resistors; if R_e and R_g are equal, the signal amplitude will be halved. Normally there is a limit on R_g because if it is made very high, the amplifier will

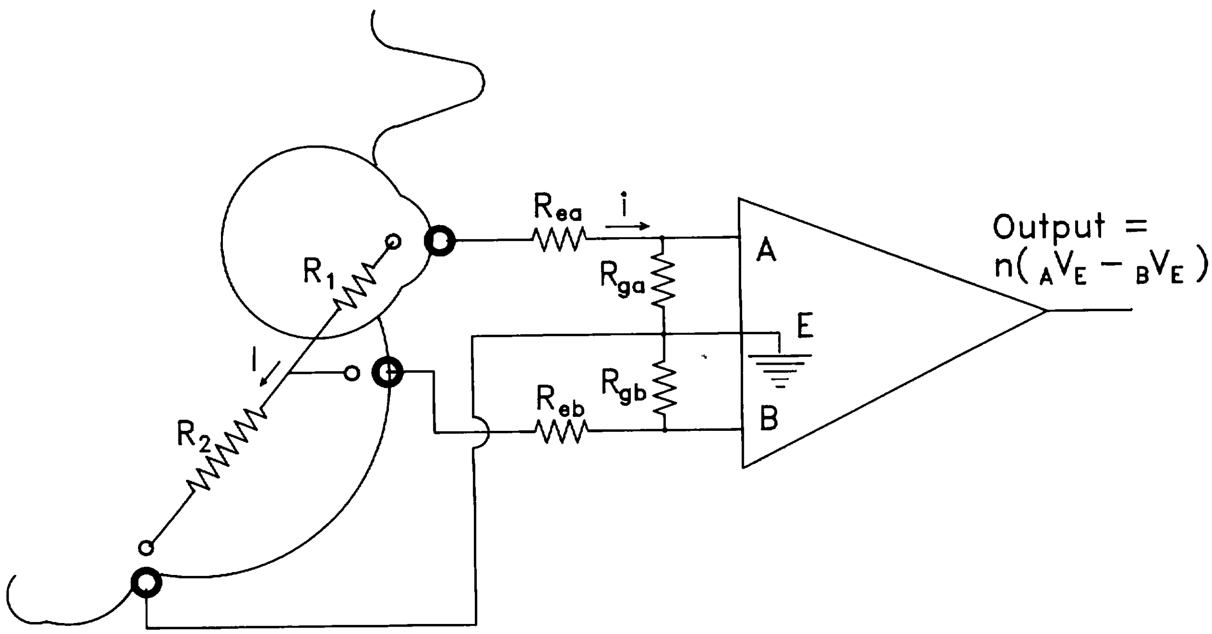

FIG 49–3.
The principle of double-sided amplification, common-mode rejection, and its degradation in practice. For further explanation see the text.

be noisy: values between 1 and 10 MΩ are encountered. Now suppose that one electrode resistance becomes very high (R_{ea}); this will unbalance the input circuit, and the signal seen by that side of the amplifier, the voltage across R_{g1}, will decrease. Therefore, the measured CMRR will decrease abruptly. In recording from the eye this imbalance almost always occurs. One electrode is a silver–silver chloride plate placed on abraded skin; the other may be a stainless steel wire placed on the cornea. If the latter polarizes, its effective resistance may be tenfold that of the skin electrode.

R_g may also change abruptly. The first stage in modern amplifiers is often a field effect transistor, and the gate of this device consists of a very thin layer of doped silicon. If an electrostatic charge is connected to the gate, e.g., by handling the electrode when its connector is inserted into the amplifier, the voltage gradient across the gate may damage it and reduce R_g. Nevertheless, if the electrodes are of low impedance, the amplifier may seem to work, after a fashion, but will be unbalanced, pick up more mains interference than previously, and will also be less stable.

When all else fails, mains interference can be removed by using a very narrow band-reject filter tuned to the mains frequency or in the main amplifier or by using a software equivalent. This is not good practice, and the filtering may itself distort the signal, especially in older equipment. The user should record the amplifier output to a series of square waves with different fundamental frequencies, with and without the "mains rejection filter" operational, to see whether the distortion is acceptable.

ELECTRODE PROBLEMS

By far and away the most common reason for encountering artifacts is poor electrode technique. For a detailed discussion of electrodes see Chapter 23. If electrodes are nominally nonpolarizable Ag-AgCl, the coating must be renewed, or else polarization will occur, and the input will be unbalanced. If exposed solder surfaces (i.e., the junction between the electrode proper and the connecting wires) come in contact with tears or saline, electrolysis will occur, and spurious slow voltage changes will be encountered.[2] Composite corneal electrodes like gold foil ones can break and develop hairline cracks that are difficult to detect but cause a high resistance. Common silver or gold skin electrodes have fewer problems but may also break at the junction with the lead. Placement of electrodes is important. The skin should be abraded with one of the proprietary abrasives to ensure an electrode resistance of $<3\,k\Omega$. The contact between skin and electrode is made with one of the proprietary contact gels and the electrode held by tape or some other adhesive medium. On the scalp the use of a modified bentonite paste is often helpful. This conducting paste is a water-soluble adhesive and holds the electrode onto hairy scalp, to which it is difficult to stick tape.

CHECKING FOR ELECTRODE PROBLEMS

Many modern systems have built-in electrode checking devices, but these work by passing current through the electrodes. Sometimes this current may be high enough to cause some damage to corneal epithelium. It is useful to have a series of "dummy patients." These consist (Fig 49–4) of three similar input wires connected together symmetrically. The simplest consists of the wire alone. When the three plugs are inserted into the amplifier sockets, the amplifier is shorted out, and the noise should disappear. If not, the amplifier is very sick! A second dummy consists of three 5-kΩ resistors joined together as shown. It is useful to have another set with 100-kΩ resistors. If these introduce hum, the CMRR has decreased. In a further variant, the three input sockets may be connected to three similar nonpolarizible electrodes that are placed in a small container of saline. If these produce the artifact, then the input stage is probably damaged. If these dummies produce a normal baseline value, the electrodes are at fault. Damaged input stages can cause slow fluctuations (drifts) of output voltage as well as higher-frequency noise and increased mains interference.

Stroboscopes require special mention. They operate at high voltages (typically 500 to 1,500 V) and discharge a high current for a very brief period. Thus electromagnetic radiations are intense and of high frequency. These penetrate shielding and are a common source of artifact that occurs at the moment of stimulation. If the artifactual voltage is small, this may be an advantage, e.g., in determining the time to peak of flicker wavelets, but frequently this is not the case. In an attempt to reduce the spikes, it is common practice to reduce the frequency response of the recording amplifier. This certainly reduces the peak height of the offending spike but also has the unfortunate effect of prolonging the declining phase of the artifact. In published records, the initial few milliseconds of the trace are sometimes removed (only for esthetic reasons, of course), but the telltail displacement of the initial portion can still be seen and the quality of the original records judged.

EYE MOVEMENTS AND OTHER MUSCLE ARTIFACTS

Some of the artifacts in recording are produced by the patient. The most common are due to move-

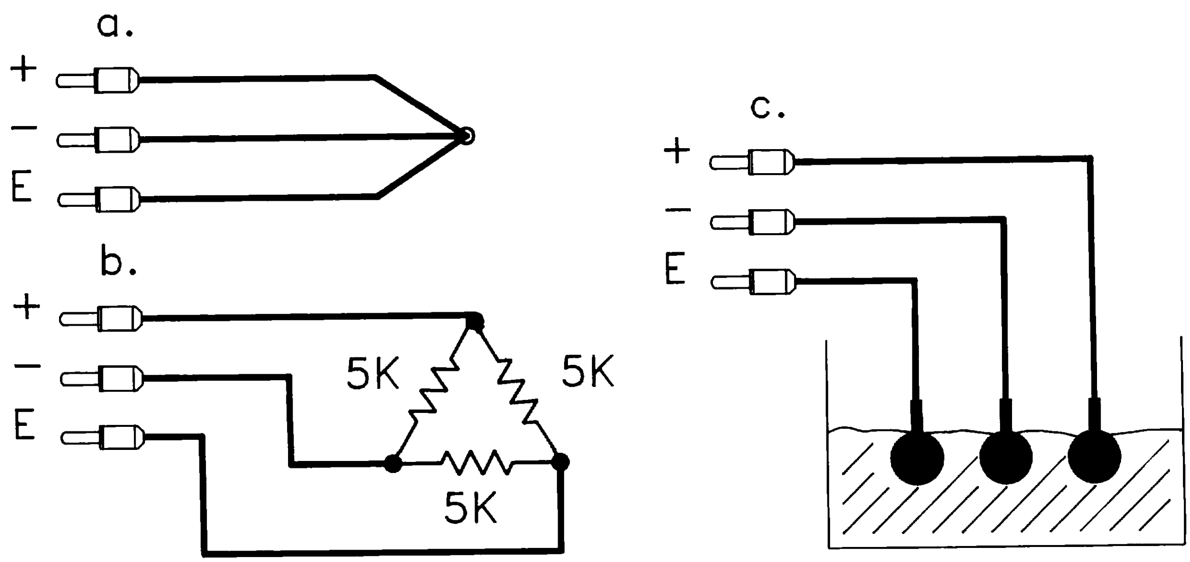

FIG 49–4.
Diagrams of "dummy patients" are useful in fault detection to short the amplifier (**A**) and to see whether noise is present when the electrodes are truly symmetrical (**B** and **C**).

ment. This can affect the electrode wires (triboelectric effect), but it is also common to pick up electrical activity from muscles: the patient should be discouraged from chewing gum! A more serious problem is concerned with eye movements and blinking. Most corneal electrodes are displaced by these movements, the only exceptions being well-fitting contact lenses made to special order. Therefore the electro-oculographic (EOG) potential at the corneal electrode changes, and this is often much larger than the response that is to be recorded. Patients with congenital nystagmus (rod monochromats, nyctalopes) therefore present a considerable problem in recording, as do those with some uncontrolled forms of midbrain degeneration. Often with patience, "quiet periods" occur when recordings can be made. A more common problem is eye movement linked in time to the flashing stimulus of the electroretinogram (ERG) or visual evoked response (VER): the flash causes the reflex blink. The delay is about 120 ms, and a large deflection distorts the b-wave. This commonly occurs in persons with photophobia, e.g., rod monochromats. Various tricks may be used to prevent blinking. If very weak flashes are used that only evoke the scotopic threshold response and minimal b-waves, blinking is less of a problem. With a light-adapted patient stimuli may be superimposed on a background and, in particular, with flicker, blinking is less evident. The provision of an adequate fixation spot may help, or the patient can be asked to make voluntary blinks before the flash is delivered. A variant of this problem occurs if the patient's eye converges or diverges after the flash. In such a case, the electrical sign of the artifact is opposite in the two eyes. The problem occurs in patients with phorias and partially compensated tropias. Again, adequate fixation may reduce these problems, but they may not vanish until there is considerable detail in the visual field, and this is not possible when the patient has to be in a completely dark adapted state. Many of these eye movement problems are reduced if a contact lens-plus-speculum combination is used, as in the Burian-Allen lens. However, smaller movements of the lids and globe still occur, and small artifacts are often more of a problem than large ones are. They may be misinterpreted and will not be rejected by any software. In addition, patients who blink and whose eyes rove are those who are most likely to show corneal problems from the Burian-Allen lens.

A further artifact has been described by Johnson and Massof[3]—a very rapid reflex response of the neck muscles to the light flash. This has a delay of about 50 ms and could be confused with the pattern ERG (PERG). Since the PERG is a very small response, such contamination is serious. The artifact is seen when the patient is uncomfortable: it occurs when the neck is extended by placing the patient in a chin rest.

Another problem when the PERG is recorded is the involuntary pendular eye movements associated with a rapidly reversing pattern that appears to "stream." The movements need not be symmetrical about the fixation spot, and therefore the PERG may be superimposed on the sloping baseline caused by the eye movement. Unless the recording contains two or more cycles of response, the measurement of extreme positive-to-negative excursions is invalidated.

Recording the VER from scalp electrodes is often easier than recording a PERG since the electrical artifacts associated with eye movements are very small for occipital electrodes. One problem that may not be evident to those without experience of the electroencephalogram (EEG) is the phenomenon of alpha-entrainment. In children especially, the alpha rhythm can become temporarily phase locked to the stimulus, and in blind eyes this is often aided by the noise made by most xenon discharge lamps when they fire. Thus a large slow wave that appears to be a flash VER can develop. The waveform very rarely resembles a VER.

AVERAGING SMALL SIGNALS: ARTIFACTS ASSOCIATED WITH AMPLIFIER SATURATION

All amplifiers in common use are ac-coupled, and the frequency response is determined by low- and high-pass filters. In most amplifiers, there are several stages of amplification, and the time constants of the intermediate stages are set to be longer than those of the initial and final stages so that further signal modification is not introduced. However, this can cause problems. If a very large and rapid potential change is amplified by the first amplifier stage, the input to an intermediate stage may be so large that its output voltage swings to the extreme value permitted by the power supply. The recovery of the intermediate stage is set by its own time constant. If the output stage has, as is usual, a smaller time constant, the output of the entire amplifier will return to zero while the intermediate stage of the amplifier is still saturated. Then the display will consist of a flat trace that appears to be noiseless. This is of consequence when very small signals are to be averaged and there are large artifacts caused, for example, by eye movements.

Most averagers reject signals that are too large, but few averagers reject signals that are too small; consequently, after a blink, the averager will continue to accept the flat trace that results from a saturated amplifier, and the final averaged signal will appear to be too small. If this artifact is known, it can be guarded against, but short of changing software and/or hardware, there is little that can be done except manual intervention.

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